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STUDIES ON VERTEBRAL INJURIES SUSTAINED DURING AIRCREW EJECTION

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TECHNOLOGY INCORPORATED

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FOREWORD

This final report covers research on Phase I of "Studies on Vertebral Injuries Sustained During Ejection," sponsored by the Physiology Branch, Biological Sciences Division, Office of Naval Research. Technology Incorporated, Dayton, Ohio, performed the research under Contract No. Nonr-4675 (00), Requisition No. NR 102-646/6-30-64, issued by the Office of Naval Research, Department of the Navy.

The scientific officer was Dr. L. Libber, Head, Physiology Branch, Biological Sciences Division, Office of Naval Research, Washington, D. C. 20360. The Branch Office, Inspector of Naval Material, 230 East 9th Street, Cincinnati, Ohio, provided contract administration.

Key personnel of Technology Incorporated engaged in this research were Dr. Lawrence S. Higgins, associate principal biomedical scientist; Mr. Stuart A. Enfield, senior biomedical research engineer; and Mr. Robert J Marshall, research statistician.

ABSTRACT

Available world literature on ejection-related vertebral injuries in aviators was thoroughly surveyed and is presented as an annotated bibliography in Appendix A. Basic findings of some of the principal investigators into vertebral injury are summarized. Parameters associated with the pilot, aircraft, and ejection-seat system are evaluated in the light of their trends and relative significance in contributing to ejection-caused vertebral injury. These studies led to the development of a proposed research design to determine the dynamic strength of isolated vertebrae. Preliminary research objectives are outlined. The experimental procedure and analysis techniques are set forth. A plan for sequencing and integrating the research operations is diagramed.

PUBLICATION REVIEW

This final report has been reviewed and approved.

James R. Braun

James R. Braun
Vice President, Research
and Engineering

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SECTION I

INTRODUCTION

Preliminary to the development of a proposed research design to determine the dynamic strength of isolated vertebrae, Technology Incorporated conducted a comprehensive survey of the available world literature on ejection-related vertebral injuries in aviators. Almost 300 literary sources were found pertinent to this subject. Abstracts of these sources are presented as an appendix.

The basic findings of some of the principal investigations into vertebral injury are summarized. Parameters associated with the pilot, aircraft, and ejection-seat system are evaluated in the light of their significance in contributing to ejection-caused vertebral injury.

The information gleaned from the literature survey provided the prime basis for the development of the proposed research design to determine the dynamic strength of isolated vertebrae. After an outline of the preliminary research objectives, the experimental procedure and analysis techniques are set forth. Then needs for test specimens, equipment, and instrumentation are listed. Finally, a plan for sequencing and integrating the research operations is outlined.

SECTION II

LITERATURE STUDY PRELIMINARY TO DESIGNING RESEARCH FOR DETERMINATION OF DYNAMIC STRENGTH OF ISOLATED VERTEBRAE

A. Historical Development of Aircraft Ejection Seats

The ejection seat for airborne escape was developed to solve the problem of the inability of aircrew members to extract themselves manually from high-performance aircraft under emergency conditions.

Early in World War II, the Germans, realizing the need for some means of assisting the pilot to escape from high-performance aircraft, began the development of an ejection seat. By the end of the war, the Germans had flight-tested ejection seats and used them operationally sixty times. The ejection seats proved satisfactory for all aircraft types except for the observer's seat in the He 219. When this ejection seat was used, the observer occasionally hit the tail of the aircraft because of the low ejection velocity resulting from jamming.

Possibly using information provided by the Germans during World War II, the Swedes developed and installed in 1945 an ejection seat in the J-21 fighter. Because of its pusher propeller and twin-boom tail with a high horizontal stabilizer, this aircraft required an ejection system to enable the pilot to escape.

Under the direction of Mr. James Martin of the Martin-Baker Aircraft Company, the British began an ejection escape study in 1944. Early in a series of dummy and human tests on an ejection seat tower, a man sustained a vertebral injury. The company developed a catapult with two powder cartridges which allowed a staged, controlled application of the ejection force to lessen the probability of vertebral injury due to rapid onset of the accelerative force. Other provisions incorporated in this ejection seat were (1) a drogue parachute to stabilize the seat and to separate the aviator from the aircraft upon ejection and (2) a face-curtain to protect the pilot's face from the wind-blast of the slip stream and to provide the means to effect initiation of the ejection sequence and to prepare the pilot for the ejection. Since the pilot had to reach overhead to pull the curtain down, the action caused him to assume a good ejection posture and to induce some tension in his spinal column so that the column could better sustain ejection loads. The first flight test of the seat with a human subject was performed in July 1946. Over the years numerous modifications, including the addition of a low-speed, low-altitude ejection capability, have been made. Most of the air services among the free nations currently use some model of this ejection seat.

Using the pattern of the German Model, the United States Air Force began the design of an ejection seat in August 1945. One year later, the first flight test of an ejection seat with a human subject was conducted at Wright-Patterson Air Force Base, Ohio. After conducting tower tests of a Martin-Baker ejection seat, the United States Navy introduced design changes and performed in November 1946 the first flight test of the modified seat with a human subject.

Further development of the upward ejection seat introduced (1) propellant charges to keep the rate of onset of acceleration (jolt) and the duration of acceleration application within physiological limitations and (2) automatic, fail-safe devices to ensure the release of the pilot restraint harness, the separation of the pilot from the seat, and the deployment of the parachute.

To extend the low-speed, low-altitude capability of the upward ejection seat to zero-speed, ground-level conditions, the U. S. Navy developed a Rocket Assisted Propulsion Ejection Catapult (RAPEC) System, which was interchangeable with the M-B catapult. The rocket catapult system has two firing phases: the first, a cartridge, produces the high acceleration needed to clear the aircraft; and the second, a rocket booster, produces the low-acceleration thrust to provide enough time and altitude for the separation of the pilot from his seat and for the successful deployment of his parachute.

Wherever practicable, such as in large aircraft with several crew positions, downward ejection escape systems have been provided. A downward ejection system has the advantages of not requiring the high ejection acceleration to clear the aircraft tail structure and of permitting escape at velocities exceeding the capability of the upward ejection system.

For emergency escape at supersonic speeds (600 mph and above) and high altitudes (50, 000 ft and above), ejection systems with a capsule, or "pod," to enclose the aircrew member have been developed. The capsule provides protection from wind-blast, restraint during deceleration, parachute descent, oxygen supply, pressurized environment, survival equipment, and flotation capability upon landing.

B. Basic Findings of Vertebral Injury Investigators

The literature offers considerable information on the physical parameters of the human vertebral column. The following summary of the findings of some major investigators is intended to indicate the information available.

1. Static Test Investigation

a. Ruff (206)

In the 1940's Siegfried Ruff conducted experiments to determine the strength of the human spinal column under the application of high acceleration for brief periods. This experimentation depended on four factors: (1) the breaking load of the vertebrae under pressure; (2) the ultimate compressive strength of the spinal column, that is, of the most heavily loaded vertebra which depended on the compressibility of the intervertebral disc, the deformability of this vertebra, and the elasticity of the upper part of the body; (3) the portion of the body weight carried by the most heavily loaded vertebra; and (4) the period of the acceleration application.

To determine the breaking strength of the individual vertebral bodies, Ruff subjected fresh, intact specimens, alone and with the intervertebral disc, to vertical, central-axis loading in a standard compression testing machine. X-ray pictures were taken of the specimens while under load to observe the processes developing within the body tissue. The breaking strength was assumed to be that load at which the stress-strain curve first peaked since the first irreparable injury to the vertebral body was assumed to occur at this point.

The capacity of the spinal column to absorb energy was investigated by loading some vertebral complexes, consisting of several articulated vertebrae, on the compression machine. The first complex tested, the six vertebrae T-10 through L-3, withstood a total load of 690 kg (1518 lb) with a deformation of 12 mm (0. 47 in.) until T-12 broke, the vertebrae absorbing 4. 5 kg-m (32. 6 ft-lb.) of energy. When the load was increased to 840 kg (1850 lb), T-11 and L-1 failed.

To determine the capacity of the lower vertebrae to absorb energy, Ruff similarly tested a complex of seven vertebrae. This complex withstood a total load of 540 kg (1180 lb) with a deformation of 4. 5 mm (0. 18 in.) until T-8 failed for an energy absorption of 1. 4 kg-m (10. 1 ft-lb.). From these tests, Ruff estimated that the entire spinal column could absorb about 10 kg-m (72. 3 ft. -lb.) of slowly applied energy before the failure of a vertebra (probably L-1). A complete spine was not tested because of its tendency to jackknife in the test rig.

The portion of the total body weight supported by individual vertebrae was found by taking X-rays of a human subject freely supported on an X-ray table. Compressive loads in 10-kg (22 lb) increments were applied to the subject's vertebral column through a yoke bearing on his head and on his feet. The strain for each incremental loading was determined by measuring the deformation of the vertebral column seen in the X-rays and then comparing these measurements with those from the X-ray of the spinal column while the subject lay prone without a load application. The distance between the vertebral bodies was then measured from a spinal X-ray taken while the subject was standing.

From the available experimental data of seat-to-head accelerations, Ruff stated that the acceleration period has the following effects on the strength of the spinal column: (1) for acceleration periods between 5 milliseconds and 1 second, the limiting factor is the static compressive strength of the weakest vertebra in the column and (2) for acceleration periods less than 5 milliseconds, the limiting factor is the dynamic strength of the weakest vertebra, which is also a function of the shock absorbing capacity of other body components, that is, the compressibility of the intervertebral discs and the elasticity of the upper part of the body. The following table containing data based on a 75-kg (165 lb) body weight summarizes Ruff's early work.

Vertebra	Compressive Strength Range		% of Body Weight Borne
	kg	lb.	
T-8	540-640	1188-1408	33
T-9	610-720	1342-1584	37
T-10	660-800	1452-1760	40
T-11	720-860	1584-1892	44
T-12	690-900	1518-1980	47
L-1	720-900	1584-1980	50
L-2	800-990	1760-2178	53
L-3	900-1100	1980-2420	56
L-4	900-1200	1980-2640	58
L-5	1000	2200	60

b. Perey (189)

To find the basic causes of lumbar vertebral injury due to static or dynamic stresses, Olof Perey of Sweden investigated specimens of many individuals. Specimens consisted of two lumbar vertebrae with the intervening disc and three lumbar vertebrae with the intervening discs. Both static compressive testing, similar to that of Ruff, and dynamic testing with a certain weight dropped a specific distance upon the specimen were performed. Test effects on the disc were determined by (1) using discographic techniques, that is, injecting radio-opaque dye into the disc and taking X-ray films, (2) recording time-related traces of pressure within the disc and (3) using cine-radiographic equipment to film the disc at 48 frames per second during dynamic testing.

Results showed that the breaking strength of the lumbar vertebrae depended on the age of the specimen. For instance, the average breaking strength averaged 425 kg.(935 lb) for specimens over 60 years of age and 800 kg.(1760 lb.) for those under 40. Resistance of the lumbar vertebral body to gradually applied compressive stresses varied between 400 kg. (880 lb.) and 1100 kg. (2420 lb.) and averaged 750 kg. (1650 lb.). Results also showed that the lumbar vertebrae could withstand a 1300-kg (2860 lb.) dynamic stress for 6 milliseconds.

c. Brown et al (29)

Brown and co-workers at Massachusetts General Hospital and Massachusetts Institute of Technology investigated the mechanical strength and elastic properties of the intervertebral discs. Using fresh specimens from routine autopsies, they investigated the axial compression, tensile strength, combined axial-load and bending, and fatigue properties of the disc. The following table lists the results of axial compression tests of vertebral combinations.

Body	Vertebrae	Ultimate Axial Compressive Load (lb.)	Axial Stiffness of Disc (lb./in.)
A	L-2, L-3	1100	18,000
	L-4, L-5	1000	15,400
B	L-3, L-4	1200	15,700
	L-5, S-1	1250	20,000
C	L-4, L-5	1300	12,000

These investigators found that the tensile strength over the surface of a disc between L-4 and L-5 varied from less than 50 to 400 lb. per square inch. The tensile strength of a disc between the third and fourth lumbar vertebrae gave values up to 400 to 700 lb. per square inch.

The axial-load bending test expanded the disc more anteriorly and posteriorly than the axial compression test. After 1000 cycles of stress during a fatigue test of less than one minute, the disc failed.

d. <u>Evans et al (68, 72)</u>

The group of investigators at Wayne State University investigated the biomechanical properties of the human vertebral column. Their work on lumbar intervertebral discs is summarized in the table below.

Vertebrae	Compressive Load (lb.)		Compressive Stress (psi)		Deformation (in.)	
	Avg.	Range	Avg.	Range	Avg.	Range
T12-L1	801	(230-1560)	430	(164-1100)	0.0796	(0.05-0.158)
L1-L2	794	(200-1495)	445	(130-1234)	0.0782	(0.043-0.100)
L2-L3	925	(240-1975)	400	(145-812)	0.095	(0.048-0.148)
L3-L4	935	(185-1505)	373	(116-705)	0.104	(0.054-0.197)
L4-L5	885	(185-1660)	377	(122-883)	0.121	(0.044-0.289)
L5-Sacrum	773	(375-1240)	292	(145-850)	0.205	(0.053-0.230)

The energy absorbed during compressive loading of the lumbar spine and pelvis ranged from 174 to 1321 in.-lb., the average being 650 in.-lb. Bending moments ranged from 173 to 437 and 213 to 391 in.-lb. in the anterior and lateral directions, respectively.

2. Dynamic Test Investigation

a. Hirsch and Nachemson

Studying the dynamic properties of the lumbar intervertebral discs, Hirsch (112) and Hirsch and Nachemson (115) found that loads applied suddenly to a disc in static equilibrium caused the disc to oscillate and induced considerable stresses in the disc because of the resultant greatly increased deformation.

Study of the literature indicates that the response of the vertebral column to dynamic loading must be investigated further before the magnitude and frequency characteristics of the vertebral column may be quantitated.

C. Significant Parameters in Vertebral Injury from Aircraft Ejection

To delineate trends in the airborne escape parameters causing vertebral injuries, the following treats of the parameters associated with the three major components involved in an ejection: the pilot, the aircraft, and the ejection system.

1. Pilot

a. Age

Pilots over 25 have had a higher incidence of spinal injury than those in the 19-24 age group. See Fryer (90).

b. Height and Weight

No trends have been evidenced in the effect of height and weight on vertebral injury. See Fryer (90) and Guill (103).

c. Training

Farmer et al (83) state that young, well-trained pilots do very well in ejection escape situations. The properly trained pilot assumes the correct body position and executes the ejection procedure efficiently. Probably because of the better utilization of the restraint harness by Navy fliers exposed to catapult takeoffs and arrestor landings, the occurrence of vertebral injuries has been significantly less in carrier-based pilots than in land-based pilots. See Smiley (224).

2. Aircraft

a. Airspeed

Airspeed affects the survival of the pilot and the degree of injuries sustained. Below 500 knots more than 75 percent of all ejections proved successful in that the pilots survived. Above 500 knots about 65 percent of the ejectees were either killed or suffered major injury. See Moseley (174) and Fryer (90).

b. Altitude

Although altitude has not affected the vertebral injury rate (see Guill (103), it has affected the survival rate. Below 500 feet, 80 percent of the ejections were fatal; and below 1000 feet, more than 50 percent were fatal. Before an improved low-altitude capability was incorporated in the escape system in 1958, virtually all ejections below 1000 feet were fatal. See "Ejection Seat Study" (62).

c. Attitude

The attitude and behavior of the aircraft at the time of ejection may affect vertebral injury if the pilot is improperly seated because of a combination of a loose harness and the acceleration forces. The inability of the aviator to reach the ejection controls and properly carry out the required ejection sequence may affect the survival rate. See Fryer (90), Davies (44), Moseley (174).

3. Ejection Seat System

a. Canopy

Ejection through a canopy which has failed to jettison was found to be a major cause of vertebral injury. Using both the Martin-Baker MK5 and Navy Standard (NAMC Type II Catapult) ejection seats, the Navy found that the vertebral injury rate for ejections through the canopy was 8.5 times the rate for ejections with a jettisoned canopy. Through-the-canopy ejections occurred

3.8 times more frequently with the Martin-Baker seat than with the Standard seat. See Guill (103).

b. Seat

(1) Martin-Baker

When using the Martin-Baker seat, the U.S. Navy, British, and Swedish experienced the following respective rates of vertebral injury incidence: 21, 19, and 43 percent.

(2) SAAB

Using the SAAB ejection seat, the Swedish experienced a 25-percent rate of vertebral injury incidence. See Jones (130).

c. Ejection Velocity

The rates of vertebral injury incidence for the types of ejection guns differed significantly; for example, the rate for the 80-ft. per second gun was higher than that for the 60-ft. per second gun. See Fryer (90).

Using the 80-ft. per second gun, the Royal Canadian Air Force experienced a vertebral injury distribution with a T-12 mode over the range T-5 to L-4. However, with the same gun, the U. S. Navy experienced a distribution with a T-10 mode over the same range. See Smiley (224).

d. Seat Pack

The elastic properties of the pack or cushion placed between the pilot and the ejection seat determine the rate at which the ejection acceleration force is transmitted to the vertebral column. If the rate of onset of acceleration exceeds the physiological limits, a vertebral injury may be sustained. See Latham (136).

e. Seat Restraint Harness

The effectiveness of the seat restraint harness in maintaining the normal vertebral column alignment during ejection is an important factor in preventing vertebral injury. Also the spinal and ejection axes should remain parallel to reduce spinal flexion and concommitant concentration of ejection loading on the anterior portions of the vertebrae. See Bosee and Payne (27).

Based on the data of Jones et al. (130), the histogram shown in Figure 1, depicts the incidence of vertebral injury for particular vertebrae. This graph combines the recent U. S. Navy, British and Swedish vertebral injury experience. Clearly, thoracic vertebrae, particularly T-12, should be the first to be investigated in any basic scientific experimentation.

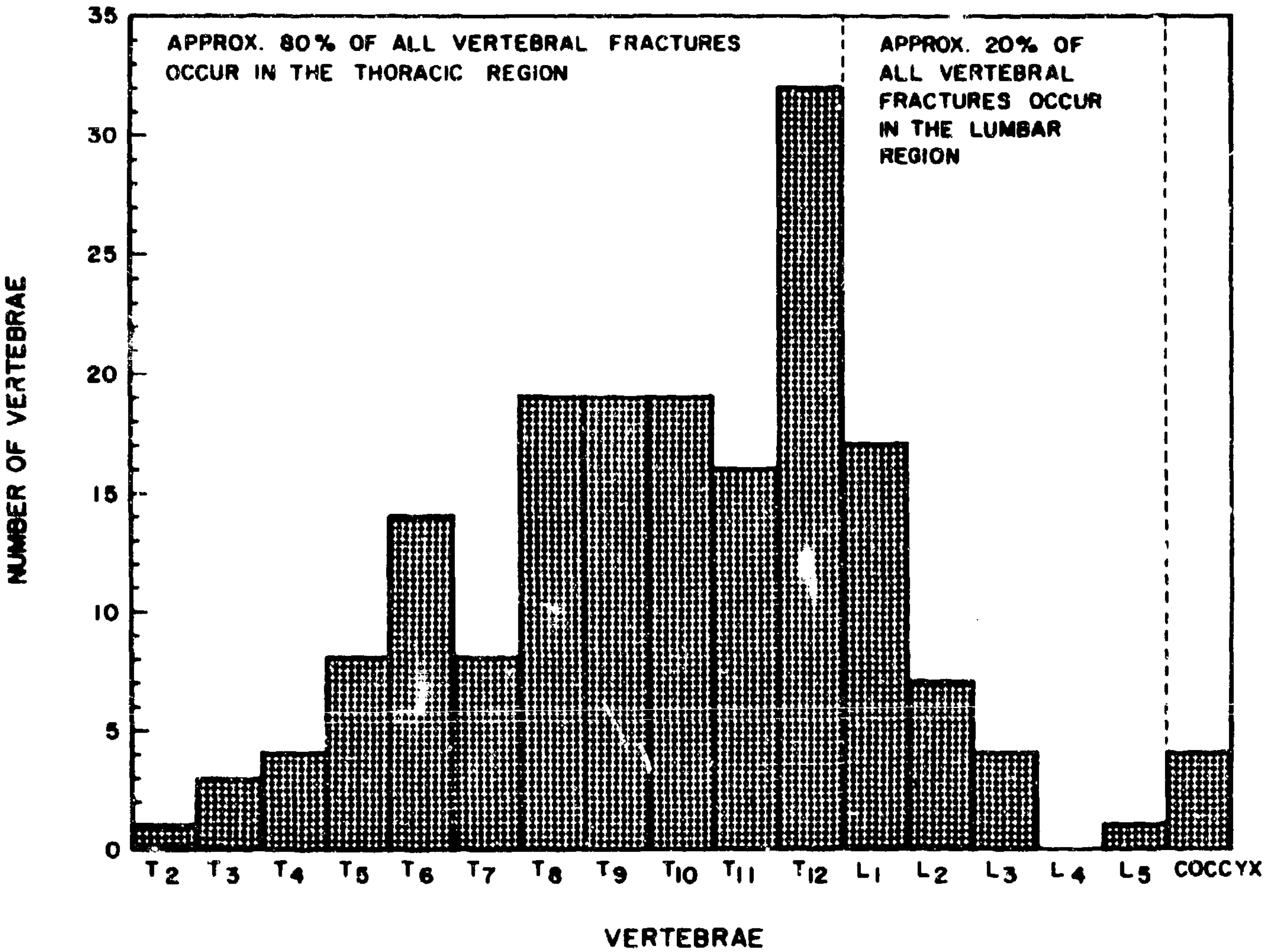

Figure 1. Incidence of Vertebral Injury in Aircrew Surviving Ejection

SECTION III

PROPOSED EXPERIMENTATION FOR RESEARCH TO DETERMINE DYNAMIC STRENGTH OF ISOLATED VERTEBRAE

Results of the literature study provided the prime basis for the development of the research proposed to determine the dynamic strength of isolated vertebrae.

A. Preliminary Research Objectives

To determine the dynamic stress-strain relationship of isolated vertebrae, the proposed research would first seek the preliminary objectives summarized as follows:

1) Determination of average anthropometry to design test fixtures.

2) Design and fabrication of test fixtures.

3) Design, fabrication, and checkout of the required specialized test machinery and associated instrumentation.

4) Bore-sighting and calibration of movie camera with test assembly; calibration of 2-dimensional deflections of bones as seen in photographic image.

5) Determination of the range of dynamic stress needed to produce a significant strain in single vertebrae so that the input levels for the complete test series may be established.

6) Statistical analysis to determine the cumulative effects of variables such as age, sex, weight, and height on the test results.

B. Experimental Procedure

Through a series of designed experiments, the first stage of research will follow the classical approach to investigate the effect in the axial direction of slow compression, impact, and sinusoidal force on vertebrae. The end product here should be an insight into the true quantitative functional form of the response, experience in handling bone specimens, verification of previous work in this area, and an indication of the direction for further experimentation.

Since past experience has shown that ejection injures the T-12 vertebra much more frequently than any other spinal segment, this vertebra will be the first subject of experimentation. Similar tests of the vertebrae on both sides of T-12 would follow. The same temperature and humidity will be maintained for every specimen tested.

The following presents three types of experiments to be performed on the selected vertebrae. If enough experimental material is available, each of the experiments will use a different group of T-12 bones.

1. Compression Test

a. Responses of Interest (Dependent Variables)

(1) Deflection of y, r_1, and r_2, the vertical height and the radii of an assumed elliptic cross section of the vertebral body.

b. Independent Variables

(1) Applied Force, F.

(2) Area of application of force, K.

(3) Calcium content of bone, C.

(4) Age of specimen, S.

(5) Radiographic density of bone if equipment is available.

Various multivariate response functions, $G(y, r_1, r_2)$, will be investigated to find that function of y, r_1, r_2 which explains the most variation from response to response by an equation involving F, K, C and S. The general form of this relation follows:

$$
\begin{aligned}
G_1 (y, r_1, r_2) = b_o + b_1F + b_2K + b_3C + b_4S + b_5F^2 + b_6K^2 + b_7C^2 + \\
b_8S^2 + b_9FK + b_{10}FC + b_{11}FS + b_{12}KC + \\
b_{13}KS + b_{14}CS + \epsilon.
\end{aligned}
$$

2. Impact Test

a. Responses of Interest (Dependent Variables)

(1) Vertical deflection, y.

(2) Rate of vertical deflection, $\dot{y}$.

(3) Deflection of major and minor axes of elliptic cross section of vertebral body, r_1 and r_2.

(4) Rate of deflection of r_1 and r_2.

(5) Rate of acceleration of y, r_1, and r_2.

b. Independent Variables

(1) Impulse, I.

(2) Calcium content, C.

(3) Age of specimen, S.

(4) Radiographic density of bone if equipment is available.

Here a general form of the response as a function if I, C, and S would be investigated as in the compression test. The general form of the equation of interest is as follows:

$$\theta\,(y,\ \dot{y},\ \ddot{y},\ r_1,\ \dot{r}_1,\ \ddot{r}_1,\ r_{2_1},\ \dot{r}_2,\ \ddot{r}_2\ ) = \gamma_0 + \gamma_1 I + \gamma_2 C + \gamma_3 S + \gamma_4 IC + \gamma_5 IS + \gamma_6 CS + \gamma_7 I^2 + \gamma_8 C^2 + \gamma_9 S^2 + \epsilon.$$

3. Sinusoidal Test

a. Responses of Interest (Dependent Variables)

(1) Displacement in each plane x, y, z.

(2) Velocities in each plane, $\dot{x}$, $\dot{y}$, $\dot{z}$.

(3) Accelerations in each plane, $\ddot{x}$, $\ddot{y}$, $\ddot{z}$.

b. Independent Variables

(1) Frequency of applied force, Q.

(2) Amplitude of applied force, A.

(3) Calcium content, C.

(4) Age of specimen, S.

(5) Radiographic density if equipment is available.

(6) Change of radiographic density if equipment is available.

Once again a general functional form of the responses measured, $\phi\,(x, \dot{x}, \ddot{x}, y, \dot{y}, \ddot{y}, z, \dot{z}, \ddot{z})$ will be investigated. The general form of the equation of interest is as follows:

$$\phi\,(x, \dot{x}, \ddot{x}, y, \dot{y}, \ddot{y}, z, \dot{z}, \ddot{z}) = \delta_0 + \delta_1 Q + \delta_2 A + \delta_3 C + \delta_4 S + \delta_5 QA + \delta_6 QC + \delta_7 QS + \delta_8 AC + \delta_9 AS + \delta_{10} CS + \delta_{11} Q^2 + \delta_{12} A^2 + \delta_{13} C^2 + \delta_{14} S^2 + \epsilon.$$

C. Experimental Analyses

For each of these experiments, the resulting multivariate regression relationship will be used to examine the following:

(1) The hypothesis that systemic disease will affect adjacent vertebrae in a like manner.

(2) The correlation between response and the order of testing which includes the order within each experiment as well as the order of the three types of experiments. Because of the complexity of the alternate hypothesis, a conclusion may be drawn only if a statistically significant correlation exists.

(3) The correlation between response and calcium content.

(4) The correlation of response and pre-existing systemic and local disease.

(5) The correlation between response and age of specimen.

(6) The correlation between response and radiographic density if equipment is available.

With a sufficient number of bone specimens, these experiments should indicate the extent of the effect of the independent variables and their interactions as well as the tolerance limits of vertebrae studied.

D. Test Specimens and Equipment

1. Test Specimens

Thirty-five or more thoraco-lumbar spines should be provided for each of the three types of experiments to ensure valid statistical analyses. The spines would be prepared by separating individual vertebrae, removing the spinous processes, and fixing the remaining body in a test fixture such as that schematically illustrated in Figure 2. Test machinery would be designed to accept the test fixture and vertebral segment without changing the configuration of the test assembly. This assembly would be so designed that an axial load would be applied to each specimen tested. Pairs of vertebrae with the intervertebral disc attached would be tested later. The latter tests would require preserving ligaments anteriorly and posteriorly since each ligament is firmly attached to the intervertebral disc.

2. Test Equipment

Specifications for each testing machine would be written during the first month of the proposed research. A standard device would likely be used for the compression tests. Devices designed by Technology Incorporated could serve for the impact and sinusoidal tests.

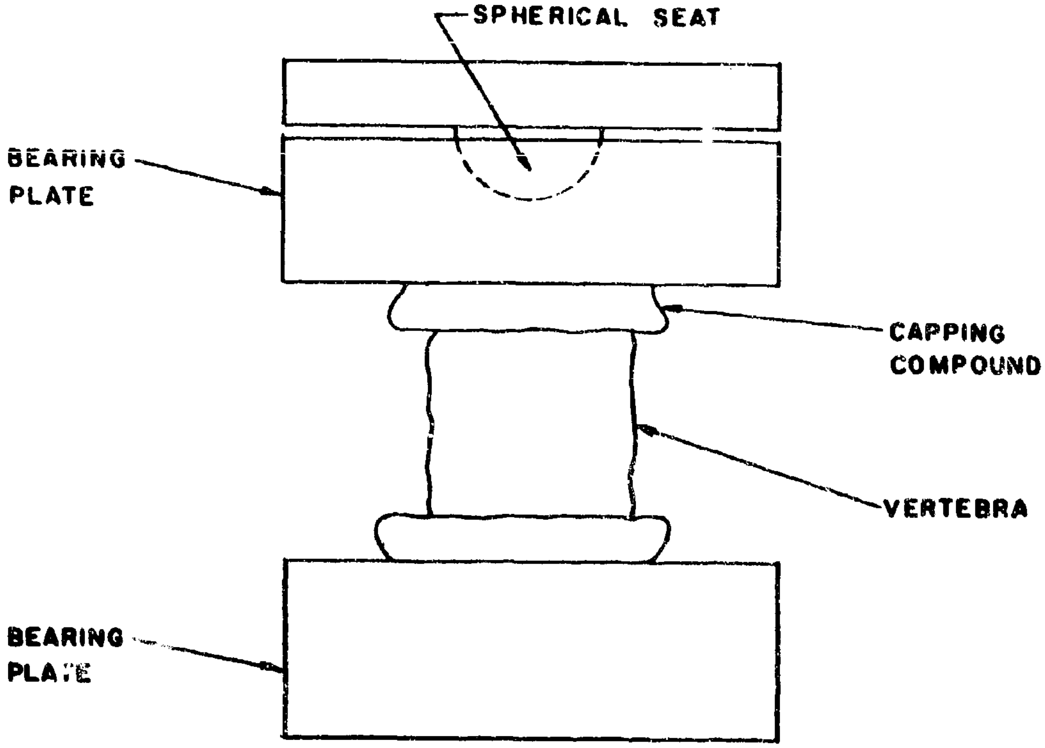

Figure 2. Typical Test Fixture to Apply Axial Load to Each Specimen Tested

E. Instrumentation

The major instrumentation needs are summarized as follows:

(1) Multichannel oscillograph with galvanometers, transducers, and excitation signal conditioning equipment.

(2) High-Speed (at least 200 frames per minute) 35-mm movie camera and mounting with developing and viewing facilities.

(3) Data reduction device for analog-to-digital conversion of information found on frame-by-frame examination of optically magnified images.

(4) If approved, X-ray apparatus to measure dynamic radiographic density of the bone in the immediate proposed tests and to measure deflection parameters of cadavers and live subjects in later phases of this investigation.

F. Plan for Sequencing Research Operations

Figure 3 presents a diagram to indicate the proposed sequencing and integration of the research operations. Operations to be conducted simultaneously are so designated. The heavy line denotes the longest or critical path for project completion. Given in weeks, the periods noted for each operation are estimates which may prove to be ± 50 percent of the actual times required.

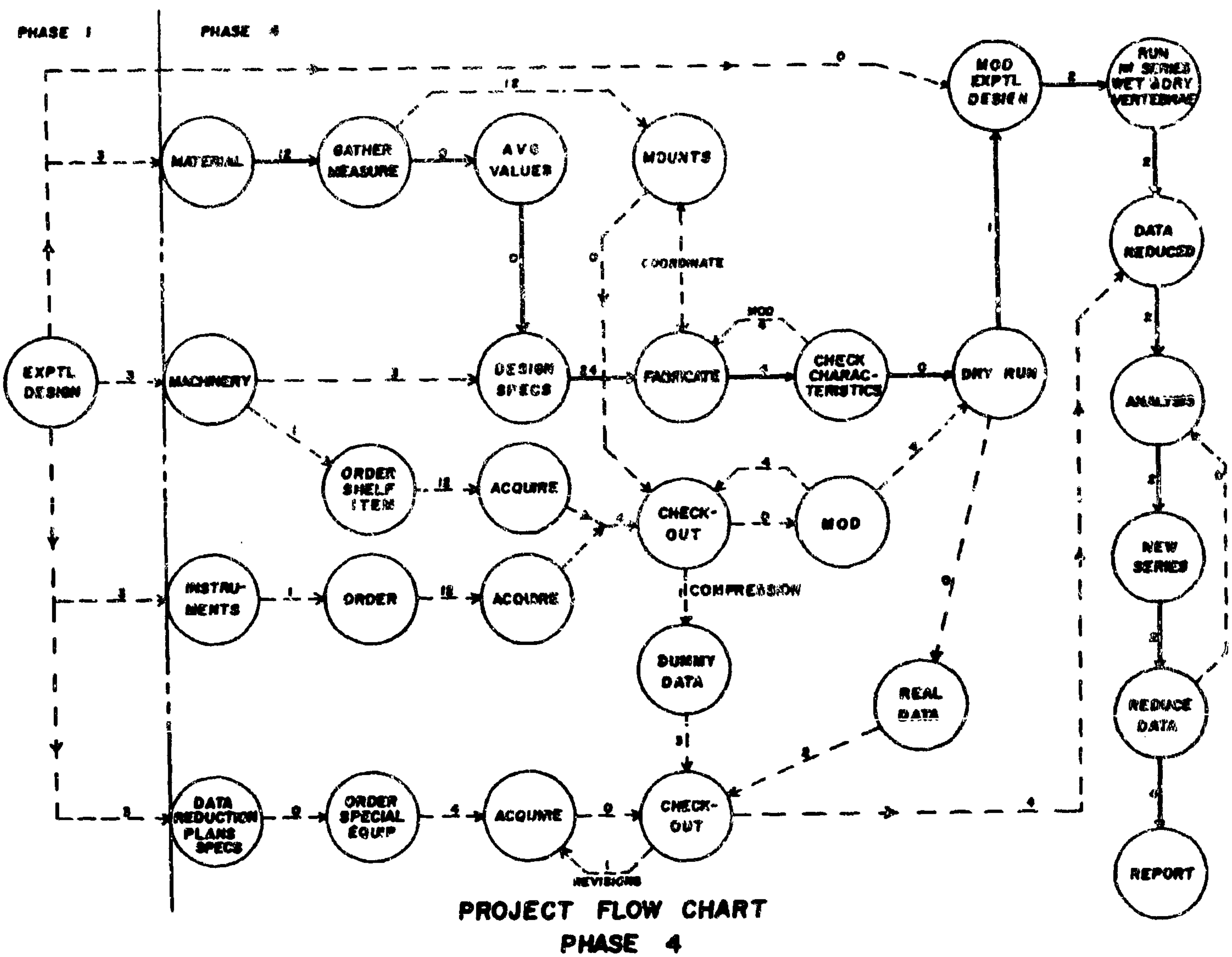

Figure 3. Flow Chart of Proposed Sequencing and Integration of Research Operation

APPENDIX A

ABSTRACTS OF LITERATURE

ON

EJECTION-RELATED VERTEBRAL INJURIES

IN AVIATORS

LITERATURE SOURCES

Listed below in alphabetical order are the agencies which provided information for the compilation of the abstracts of the literature on ejection-related vertebral injuries in aviators.

1. Aerospace Medical Library
   Building 29, Area B
   Wright-Patterson Air Force Base, Ohio

2. Aerospace Medical Research Laboratories
   Aerospace Medical Division
   Wright-Patterson Air Force Base, Ohio

3. Armed Forces Institute of Pathology
   Washington, D. C.

4. Armed Services Technical Information Agency
   Arlington Hall Station
   Arlington 12, Virginia

5. Aviation Safety Engineering and Research
   Division of Flight Safety Foundation, Inc.
   2641 East Buckeye Road
   Phoenix, Arizona

6. Civil Aeromedical Research Institute
   Federal Aviation Agency
   Aeronautical Center
   P.O. Box 1082
   Oklahoma City, Oklahoma

7. Cornell Aeronautical Laboratory, Inc.
   Cornell University
   Buffalo, New York

8. Defense Documentation Center
   Building 47, Area B
   Wright-Patterson Field, Ohio

9. Defense Documentation Center, Headquarters
   Defense Supply Agency
   Cameron Station
   Alexandria, Virginia 22314

10. Defense Research Medical Laboratories
P. O. Box 62, Station 'K'
Toronto 12, Ontario, Canada

11. Department of the Navy
Bureau of Medicine and Surgery
Washington, D. C. 20390

12. Directorate of Flight Safety Research
Office of The Inspector General
United States Air Force
Norton Air Force Base, California

13. Douglas Aircraft Company, Inc.
3855 Lakewood Blvd.
Long Beach, California

14. Library of Congress
Science and Technology Division
Washington, D. C.

15. LTV Vought Aeronautics
P. O. Box 5907
Dallas, Texas 75222

16. Miami Valley Hospital
One Wyoming
Dayton, Ohio

17. National Academy of Sciences
National Research Council
2101 Constitution Avenue
Washington 25, D. C.

18. National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

19. National Library of Medicine
Public Health Service
8600 Wisconsin Avenue
Bethesda, Maryland 20014

20. National Referral Center for Science and Technology
Library of Congress
Washington, D. C. 20540

21. North American Aviation, Inc.
4300 E. Fifth Avenue
Columbus, Ohio

22. School of Aviation Medicine
Aerospace Medical Division
Randolph Air Force Base, Texas

23. Stanley Aviation Corporation
P. O. Box 20308
Denver, Colorado 80220

24. Technical Library
Building 12, Area B
Wright-Patterson Air Force Base, Ohio

25. U. S. Department of Commerce
Office of Technical Services
Washington, D. C.

26. U. S. Naval Aviation Safety Center
U. S. Naval Air Station
Norfolk, Virginia 23511

27. U. S. Naval School of Aviation Medicine
Pensacola, Florida

28. Wilford Hall USAF Hospital
Aerospace Medical Division
Air Force Systems Command
Lockland Air Force Base, Texas 78236

1

"A Hasty Exit," Aircraft (Toronto), 13: No. 6, 12-15, June 1951.

ABSTRACT: Above 155 mph the pilot needs help in bailing out because of the danger of being struck by some part of the plane. Above 400 mph wind resistance makes getting out of the cockpit a considerable feat of physical strength. Accelerative forces may make it impossible for the pilot to lift himself from his seat.

Taking all these factors into consideration, England's Martin-Baker Aircraft, Ltd. (which has been working on the problems since 1944) concluded that the best way to leave an aircraft was to be shot out of it. This not only effectively overcomes the imprisoning G forces, but also removes the airman to a point well clear of any part of the airframe.

The basic mechanism of the ejection seat is simply a gun—a pair of telescopic tubes (the inner one being the projectile) which are normally locked together by a gas-pressure-operated lock that frees the seat at the moment of explosion. The gun is located inside a hollow guide rail. Mounted at an angle of backward slope, it may be attached in various ways suitable to the structure of the particular aircraft. The seat is moved along this guide rail by the action of the gun, and leaves the aircraft at 60 feet/second.

Human G tolerance complicates the problem. Not only must the seat and its occupant be thrown about 80 feet in the air but the acceleration must be progressive and uniform. The Martin-Baker seat develops a maximum G force of only 18.75, at about 1/8 second, after the gun is fired. The maximum rate of acceleration is about 200 G/second, spread over a total elapsed period of 1/5 second (the time it takes the seat to move the full 42" of the gun stroke).

Martin-Baker has carried out experiments in which the initial acceleration was 600-700 G/second. Apart from the fact that this would be too much for the human body to stand, it still was not enough to throw the seat high enough to clear the aircraft. The seat lifted only 20 feet, whereas by the progressive acceleration method it reaches 80 feet (probably because the natural inertia of the seat is overcome gradually and with less waste of energy). 18.75 G, applied progressively, does not cause blackout. Blackout occurs when, upon acceleration applied for a sufficient length of time, blood drains from the eyes and brain. There is temporary loss of sight followed in some cases by loss of consciousness. The time factor is important. Thus, 5 G for up to about 5 seconds will not cause blackout. In the Martin-Baker seat, the 18.75 G is applied for only about 1/8 second, which is not enough to overcome the blood's inertia and to cause blackout.

The Mark III Automatic, Martin-Baker's latest model, differs from the Mark I in that ejection, release from the seat, and release of parachute are almost automatic—the pilot only sets it in motion by firing the primary cartridge. After

jettisoning his canopy the airman withdraws his feet on to the ejection footrests and pulls the firing handle, thereby withdrawing the face screen and ejecting himself with the seat from the aircraft. A static line next fires the drogue gun, which withdraws from the parachute pack the small drogue attached to the top of the seat and retards and stabilizes it. A barostat-controlled timing device, set in motion as the seat is ejected, releases the drogue from the seat after a delay of 4 seconds, provided the seat is below 10,000 foot altitude. Release of the drogue frees the harness locks which attach the airman and his parachute pack to the seat, and the drogue withdraws the parachute from the pack, which supports the airman while the seat falls away.

As long as the pilot can start the ejection sequence, even though he loses consciousness he will be safe. If G forces in the plane are so great that he cannot lift his feet from the floor, the foot rests are designed so he has only to slide them into the foot rests. The action of pulling the face screen down places the airman's arms in the best position for ejection and protects his face from wind blast. The seat and everything to do with it, including the harness, are stressed for up to 25 G.

Besides the CF-100, Martin-Baker seats are installed in such aircraft as the Gloster Meteor 8, the Westland Wyvern, the English Electric Canberra, the Hawker P-1081, the Vickers-Armstrong Attacker, the de-Havilland Venom, and the Vampire. It is being sold to Canada, France, Switzerland, Belgium, Holland, India, Pakistan, and the Argentine.

2

Achiary, Terneau, and Buchet, "Vertebral Injuries in Flying Personnel (Traumatismes Vertebraux du P. N.)," Rev. Med. Aero. (Paris), 7(4):371-374, 1952.

ABSTRACT: A discussion of nine cases of vertebral injury observed at the French Center of Flight Training in Brittany in less than three years. Four cases were due to airplane crashes, two cases were from helicopter accidents, two were injuries to parachutists and one due to catapulting on the ground. The necessity of a systematic examination, including a rigorous radiological study, in this type of case, was emphasized.

3

Achiary, A., T. Servanty, A. Cabanon, and V. Andre, "Dynamics of the Ejection Seat(La dynamique du siege ejectable)," Rev. Med. Aero(Paris), 11(1): 55-58, 1956.

ABSTRACT: Characteristics of the accelerative forces imposed by ejection and the dynamic relation between accelerations of the seat and its occupant are discussed. It is shown that the discrepancies between accelerations of the seat and

the body parts, as well as the physiological dangers of ejection, are dependent on the elasticity of the body and on seat cushion hardness.

4

Aho, A., and E. Tahti, "Significance of Functional Radiography of the Lumbar Spine in Forward and Backward Flexion," Annales Chirurgiae et Gynaecologiae Fenniae (Helsinki), 46(3): 333-350, 1957.

ABSTRACT Functional radiography of the lumbar spine was found to supplement conventional radiography. The diagnosis from functional radiography was based on exceptionally restricted mobility or exceptional mode of movement of the intervertebral space.

Exceptional mobility was almost always associated with symptoms from the lumbar spine. Exceptional segmental mobility disclosed intervertebral degeneration. Exceptional mode of movement can often be considered an indication of incipient degeneration of the nucleus pulposus. A considerable and exceptional restriction of movement is a radiological symptom of more advanced intervertebral degeneration. In the event of radiating pain, functional radiography helped to localize the prolapsed segment in acute cases of recent origin.

5

Aircraft Type 29, Ejections by Catapult Seat, ATIC-235370, Air Technical Intelligence Center, Wright Patterson Air Force Base, Ohio, F-TS-8748/III, ASTIA AD 153-353, 1952.

ABSTRACT: This report describes the circumstances leading up to an ejection and the procedures used during several ejections. It also describes the injuries to personnel as a result of ejection.

6

"Aircrew Comfort and Survival," The Aeroplane (London), 96(2481):348-350, 20 March 1959.

ABSTRACT: A general discussion is presented of control systems, equipment, and techniques utilized by the Royal Air Force to insure the comfort and survival of its airmen in the newer high speed, high altitude aircraft. General performance capabilities and operating procedures are outlined for cabin pressure control systems, temperature and ventilation control systems, oxygen systems, and pressure suits and helmets. Ejection seats, parachute assemblies, aircraft dinghies, and emergency radio units are also discussed. Names of manufacturers and illustrations of various items of equipment are included.

7

Ames, W. H., H. M. Sweeney, and H. E. Savely, "Human Tolerance to Acceleration in Pilot Ejection," J. of Aviation Medicine, 18(6):548-533, Dec. 1947.

ABSTRACT: In view of individual variations, it is apparent that the accelerations applied to the subject should be kept to the minimum required to achieve the desired terminal velocity and that the rate of application of the g forces be kept as low as possible. The present ejection seat equipment developed by the Army Air Forces and the Ordnance Department provides a terminal velocity of 60 feet per second with a maximum of 14 to 16 g on the subject at a rate of application of 175 to 200 g per second. This system provides a means of emergency escape from high speed aircraft with a maximum g well under what is considered the physiological tolerance to high linear acceleration.

In service use, it is evident that a thorough indoctrination should be given all pilots of aircraft equipped with ejection seats so that they may become conditioned to the sequence of events prior to ejection and appreciate the necessity of assuming the proper body position. This indoctrination should consist of a demonstration of the equipment, movies of actual live ejections, such as the two made in August, 1946, at Wright Field, and an ejection on the 100-foot ejection seat test tower.

8

Ames, W. H., "Human Tolerance to High Linear Accelerations of Short Duration," Military Surgeon, 103(2): 96-99, August 1948

ABSTRACT: The results of the studies conducted by the Air Material Command on the factors involved in human tolerance to high accelerations of short duration as applied from head to foot.

9

Ames, W. H., and H. E. Savely, "Motion of the Head During Simulated Seat Ejection," MCREXD 695-661, Engineering Division, Air Materiel Command, U.S. Air Force, ASTIA ATI 67 688, 6 January 1948.

ABSTRACT: This report contains the results of studies to determine the effects of fore-aft adjustment of the head rest on motion of the head during simulated ejection on a test tower. After completion of the tests, it was concluded that the danger of injury to the neck during simulated seat ejection on a test tower can be effectively controlled by proper fore-aft position of the head rest and the assumption of the proper body position. If hyperflexion of the neck occurs during accelerations of approximately 12 g or over, some degree of injury to the neck can be expected. No experimental methods are available for assessing the degree of injury which may occur.

10

Arment, D. E., and R. C. Lenz, "Kinetic Measurements on a Pilot Dummy Ejected From a P-61 Airplane in Flight, Detailed Analysis of Data," Serial No. TSEAC12A/4303-45-1, Air Materiel Command, Wright Field, Dayton, Ohio, ASTIA ATI 186 676, 17 October 1946.

ABSTRACT: This report presents the data and the analysis thereof, relative to the forces acting on the pilot-dummy during the ejection-seat tests conducted with the P-61B-5 airplane during the period from 27 February 1946 to 1 April 1946. Detailed studies of the kinetic measurement data resulted in the following conclusions: (a) The ejection velocity (57.6 f.p.s.) obtained in the tests closely approximates the velocity (57 f.p.s.) for which the catapult was designed. (b) At airplane velocities greater than 235 mph indicated airspeed, the horizontal acceleration caused by the airstream exceeds 3 g. The horizontal acceleration becomes physiologically negative if the ejected pilot should rotate to a head-forward position. (c) The increased horizontal acceleration at the higher airspeeds makes reduction of the ejection velocity inadvisable because the pilot's trajectory might approach too close to the tail of the airplane. (d) The vertical acceleration, as recorded for the peak values (27 to 31 g for 0.015 second), exceeds the present-known physiological tolerance of a human subject. (e) The peak "vertical" accelerations were caused by the compressibility of the parachute packs between the seat and the dummy, and probably can be eliminated or reduced by corrective modification of the cushioning components.

11

AT SUPERSONIC VELOCITY, Trans. No. FTD-TT-61-203 (Sovetskaya Litva, p. 3, 28 July 1961), Foreign Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, 27 November 1961.

ABSTRACT: New types of ejection seats were developed in recent years. Instead of pyrotechnic cartridges, they use rocket engines. The most perfect samples allow ejections at velocities up to 2400 km/hr. Developed also were the first samples of special safety capsules. They are like small cabins formed by extensive walls. Such a capsule closes automatically and becomes hermetically sealed prior to catapulting, offering protection against counter stream of air, and safe landing. In addition, it serves as a container for rescue devices (Parachutes, emergency supply, oxygen equipment, etc.) and as a rescue raft in case of falling into the water.

12

Barash, I. M., The Etiology and Prophylaxis of Vertebral Fracture in Crash Landings, Enclosure 9 to Report E-553, Chance-Vought Aircraft, Inc., Dallas, Texas, 13 February 1956.

ABSTRACT: An account of the recent experimental research conducted on evacu-ation at low altitudes and the present state of this question are discussed.

'he problem of the opening of the parachute at high speeds constitutes a funda-nental difficulty at speeds inferior to 600 miles per hour. The questions relative physical protection against "slap" (air blast) and the forces of abrupt deceler-ion are studied at speeds up to 800 miles per hour.

avies, J., The Problem of Back Fractures During Ejection from USAF Air-craft. Period: 1 August 1949 thru 31 March 1956, Publication 2-57, AFR 190-16, Norton Air Force Base, Calif., January 1957.

BSTRACT: This study concerns the frequency and causes of back fractures which ere experienced during ejection escape from USAF aircraft.

review of ejection escape experience from USAF aircraft for the period 1 August 949 through 31 March 1956 revealed that 5% (32) of all nonfatal ejections involved ack fractures. Fourteen personnel believed their fractures occurred during fir-ig of the seat, 7 on landing, 2 when the chute opened, 2 on contact with the canopy, nd 7 at unknown or indefinite times. Three of the latter 7 were reported as possi-ly occurring when the seat fired.

'he major cause of fractures occurring when the seat fired was poor body position. oor body position during ejection was a result of: undesirable aircraft attitude, ack of effort or time to prepare for ejection, inability to use the headrest, and eaning forward to look at or reach the ejection trigger.

ractures during firing of the ejection seat have occurred only in F-86, F-84, -94, T-33 and B-52 aircraft. These facts indicate a need for further investiga-ion of the role ejection seat configuration, filler blocks and survival kits play in ausing or preventing back fractures during ejection.

resent available data does not indite any particular aircraft type or model as eing particularly hazardous with regard to back fractures during ejection.

he incidence of back fractures during ejection escape can be reduced by:

. Greater training emphasis on:

a. The necessity for proper ejection position.
b. The use of proper equipment in the seat.
c. Correct parachute fitting, opening and landing techniques.

. Additional research and improved design with regard to seat configuration and equipment used in the seat.

13

"Bang! You're Alive!", Air Clues, 13(3):66-73, December 1958

ABSTRACT: This article traces the development of ejection seats. The name of the British firm of Martin-Baker is synonymous with ejection seat history and much help has been received from them in writing the article. The many changes in the design of the seats are not detailed and an outline only of the main events is given. The article contains many new facts, and a number of the photographs have not previously been published.

14

Barrett, S., and P. R. Payne, The Response of a Linear Damped Dynamic System to Selected Acceleration Inputs, Frost Engineering Development Corporation, Englewood, Colorado.

ABSTRACT: The general theory is developed for the response of a single degree of freedom, lumped parameter dynamic system to an arbitrary acceleration forcing function. General closed-form solutions are obtained for the response of a linear damped system to a variety of discrete pulse shapes, and the form of the solutions indicated for oscillatory forms, and semi-infinite ramps.

In previously published work of this type solutions have only been obtained for un damped systems. Since almost all dynamic models of the human body involve damping, the need for the extensions given in this paper is obvious. When the coefficients of a dynamic model are known, together with the critical deflection, Figures 4 through 9 can be used to construct injury curves for the relevant pulse shapes, while the theory developed in the main body of the report can be used to generate solutions for other pulse and oscillatory input shapes.

15

Barton, J. A., Investigation of Back Injuries Sustained by Pilots in Event of Nose Gear Failure on Landing, Report E-533, Chance-Vought Aircraft, Inc., Dallas, Texas, 13 February 1956.

ABSTRACT: Investigation and evaluation of a film record of an aircraft accident during landing of an F7U-3 aboard the aircraft carrier USS Ticonderoga on 7 Jan. 1956 showed:

1. The forces resulting in back injuries are caused by excessive horizontal deceleration due to the manner in which the aircraft and arresting gear performed, coupled with high vertical impact loads applied as the nose section contacted the deck subsequent to failure of the nose gear.

2. The inability of the present type shoulder harness to restrain the pilot both horizontally and vertically allows these forces to act upon the body in such a manner as to cause injury to the vertebral column.

This report contains plots of the graphical analyses of the film record, enclosure 8 by Dr. J. R. Poppen, entitled "Notes on Study of Back Injuries in Case of Nose Gear Failure," and enclosure 9 by Capt. Ira M. Barash, entitled "The Etiology and Prophylaxis of Vertebral Fracture in Crash Landings."

16

Barwood, A. J., "The Maintenance of Correct Ejection Posture," Aerospace Med., 34(7):618-621, July 1963.

ABSTRACT: The high incidence of mild back injury during otherwise successful ejections, and the increasing incidence of such back injury with the improvement of ejection capability, prompted investigation into the probable cause of such injury. The geometry of harness systems was studied and the techniques for adjusting such harnesses were investigated. The typical back injury in the region of T-10--L-2 indicated that posture appeared to have a direct relation to such injury. Means of maintaining an acceptable posture were therefore investigated and ultimately modifications for all types of harnesses were proposed. Initially these were tried experimentally and have produced marked improvement in whole body restraint, and have, at the same time, made the harness system more comfortable. The moulding of the seat top and back to the mean anatomical profile of aircrew has also been attempted, resulting in the maintenance of an improved ejection posture and very considerable improvement in comfort and acceptability -- a factor which might well be applied to conventional seats.

17

Beer, M., R. M. Jayson, V. E. Carter, and F. H. Kresse, Survey of Escape Training in the Air Force, WADD Technical Report 60-792, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, ASTIA AD 255 917, March 1961.

ABSTRACT: The present state of the Air Force ejection training was studied and its contribution to the overall ejection problem was considered. Relevant information was obtained from the literature on ejection training, training films, aircrew personnel, aircrew personnel who have ejected, accident statistics, and escape training instructors. The results showed that ejection training is inadequate in content and frequency. There is a lack of standardized regular training programs. Furthermore, training media, such as ejection seat trainers and films, leave much to be desired in both quantity and quality. Even more important, training to reduce fear of and anxiety about ejection is needed. In general, aircrew personnel "know" when to eject; but hesitate to take action because of an inadequate knowledge of procedures and an anxiety produced by unfamiliarity with the ejection experience. Ejection training in the Air Force is inadequate and needs to be improved.

18

Bell, H. S., and S. P Chunn, "Summary and Evaluation of Aircraft Accidents and Fatalities," Aerospace Med., 35(6):553-559, June 1964.

ABSTRACT: There is a requirement for more thorough investigation and reporting of all factors involved in aircraft accidents and incidents, in order to reduce the number of accidents which are presently classified as "undetermined."

There is a requirement for more frequent periodic training which will stress the importance of psychophysiological factors involved in present accident experience. Such training, conducted by Physiological Training Officers, Flight Medical Officers, and Flight Surgeons, will be in addition to required physiological training. It must be consistent with current operational aircraft and, when possible, under realistic conditions.

Aircraft accidents are progressively more critical particularly in high-speed aircraft, in that the per cent of major accidents which involve fatalities is consistently increasing. Therefore, there is a need for emphasis on the decision to eject at a safe altitude and training in the use of mission aircraft equipment. Crash landings in high performance aircraft are untenable. Improvement in low-level escape capability is a definite necessity. In addition, it is recommended that periodic training be conducted which will stress the importance of proper parachute landing technique in order to reduce injuries.

There is a need for an active and aggressive program which will be devoted to the improvement of all required items of personal equipment expeditiously, i.e., research, development, evaluation, procurement and distribution. It is recommended that the required items be based on the minimum, practical necessities for survival. Further, it is recommended that an effective personal and crash locator beacon be obtained as soon as possible. Such devices will expedite the location of downed crewmembers and the crash site.

19

Bergeret P., ed., "Escape and Survival: Clinical and Biological Problems," Aerospace Med., AGARDograph No. 52, ASTIA AD 261 881, 1961.

ABSTRACT: This collection of monographs is published for and on behalf of AGARD NATO (Advisory Group for Aeronautical Research and Development, North Atlantic Treaty Organization). Contributed by experts in the field, the papers discuss various aspects in the study of clinical and biological problems in aero space medicine on the subject of escape and survival.

20

Bezreh, A. A., "Army Experience with Crash Injuries and Protective Equipment," presented at Symposium on Biomechanics of Body Restraint and Heat Protection, Naval Air Material Center, Philadelphia, Pennsylvania, June 1961.

21

Bibliography of Aviation Medicine in Japan (Wagakuni ni Okeru Koku Igaku Bunken Mokuroku, Tokyo, Japan), Aeromedical Laboratory, JASDF, 1 July 1963.

ABSTRACT: This is a bibliography of the Japanese literature on aerospace medicine (without abstracts). The references are grouped in the following categories: General; Basic Aviation Medicine; Clinical Aviation Medicine; Aviation Phychology; Aptitude Tests; Human Engineering; Accidents; Air Transportation; Space Medicine; and Aerospace Science.

22

Bierman, E. O., "Trauma Following Ejection from Jet Aircraft: A Case Report," Am. J. Ophthal., 48(3, Part I):399, September 1959.

ABSTRACT: A 34-year-old man, ejected from a jet aircraft at approximately 18,000 ft. at a speed of over 600 miles per hour (0.9 the speed of sound), sustained a multiplicity of broken bones, subconjuntival hemorrhages, marked extravasation of the eyelids, and marked swelling of the face and lips. Examinations within a few hours after the accident and two months later revealed no damage to the eye itself.

23

Bondurant, S., Optimal Elastic Characteristics of Ejection Seat Cushions for Safety and Comfort, WADC Technical Note 58-260, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, ASTIA AD 203384, 1958.

ABSTRACT: Ejection seat cushions of low compression resistance and/or great thickness may significantly magnify the force acting on the occupant of the seat, thus increasing the likelihood of vertebral injury. Cushions of the compression resistance used in this study which exceed 3.5 in. in thickness were found to amplify the g force acting on the seat occupant while the use of a 1 to 3-in. cushion decreased this force. RAF studies in this field have led to replacement in RAF aircraft of all foam rubber ejection seat cushions with plastic cushions. Studies at the Aero Medical Laboratory have shown the danger of the A-5 cushion because of low compression resistance and considerable thickness and the improvement in safety and comfort afforded by the MC-1 and MC-2 cushions of medium density foam rubber. Moreover, these studies are in aggreement with those of the RAF in suggesting that further improvement could be effected by use of a suitable plastic cushion. The Aero Medical Laboratory studies show that a standardization procedure for evaluating seat cushions should be established. In Addition, it was determined that safety testing of all seat cushion designs should be conducted through a series of test ejections with human subjects until further studies provide a suitable mechanical test.

24

Bosee, R. A., "Accessory Equipment and Testing Problems: Problems of Escape from High Performance Aircraft," J. Aviation Med.; 28(1):83-90, Feb. 1957.

ABSTRACT: Recently developed ejection seats with automatic harness releases and altitude-controlled parachute deployment devices permit comparatively safe ejection from high and low altitudes at subsonic speeds. The reefed parachute, currently being tested, will permit more stable descent from high altitudes and will offer a very low opening shock. The escape capsule does not seem to be desirable in high-speed, low-altitude escapes (the majority of ejections occur at relatively low altitudes). An aerodynamically stabilized seat and a "cocoon-like" protective covering for the pilot may be more suitable for this purpose, since the wind blast forcing his body against the seat would tend to evenly distribute the decelerative g forces.

25

Bosee, R. A., and W. C. Buhler, "Escape from Vertical Take-Off Aircraft," J. Aviation Med.; 26(4):319-322, 1955.

ABSTRACT: The U. S. Navy Bureau of Aeronautics has exploited a radically new concept in fighter type aircraft. Standing on their tails like rockets, the turbo-prop powered Lockheed XFV-1 and Convair XFY-1 take off vertically.

In an effort to reduce pilot confusion during emergency ejection, the escape procedure for vertical take-off (VTO) aircraft has been simplified. A completely automatic escape sequence has been devised, tested and installed in both the Lockheed XFV-1 and Convair XFY-1 aircraft. The system is outlined and described in this article.

26

Bosee, R. A., and C. T. Koochembere, "Naval Aircraft Escape Systems-Past, Present, and Future," Aerospace Med., 32:223, March 1961. (Abstract) Aircrew Equipment Laboratory, Naval Air Material Center, Philadelphia, Pa.

ABSTRACT: Escape systems as defined in this paper encompass the ejection

seat concept as applied to naval operational and training type jet aircraft. It is also applicable to those escape systems that have been considered for vertical takeoff and landing (VTOL) types. The evolution of seat and seat catapult design as well as performance capabilities are described as they relate to post World War II naval aircraft. The need for increased ejection trajectory height to assure ground level escape is documented. Test and development relative to some early escape capsule designs as well as a description of some energy attenuation systems are presented. The transition from sixty feet per second to eighty feet per second ejections in conventional seat catapult is explained. The effect of acceleration as applied to seat occupant and equipment is described. The design and function of rocket-type ejection seat systems for more advanced type manned military aircraft and tests to assure performance, reliability and personnel compatibility are also set forth. Finally, an experimental integrated flight capsule concept is described in which a shaped charge is used to cut the capsule away from the remainder of the aircraft.

27

Bosee, R. A., and C. F. Payne, Jr., "Theory on the Mechanism of Vertebral Injuries Sustained on Ejections from Aircraft," presented at Aerospace Medical Panel of the Advisory Group for Aeronautical Research and Development, ASTIA AD 256 378, April 1961.

ABSTRACT: If the body must be supported by the spinal column during ejection, it is improtant to maintain: (1) The normal vertebral alignment; (2) The normal spinal axis; (3) Parallel ejection and vertebral axes. This will result in good body posture and therefore good force distribution on the weight-bearing portions of the vertebrae.

28

Bourret, A. S., J. Fabre, and J. Divine, "Physiological Study of a Sonic Ejection Having Caused Heavy Injuries (Etude Physiologique d'une Ejection Sonique ayant Entraine des Lesions Graves)" Revue des Corps de Sante des Armees Terre Mer Air, 4:577-588, October 1963.

ABSTRACT: A double ejection at 0.35 Mach is reported with the French E. 96 and E. 97 ejection seats where the subjects (pilot and navigator) survived after sustaining severe injuries. The ejections were carried out at 10,000 and 15,000 feet. The pilot's main injuries included severe dislocation of both knees and right arm, and petechias of the face, neck, arms, etc. The navigator sustained dislocation of the right elbow, fracture of the femur, and sub-capital fracture of the left humerus. Although the mechanical apparatus of the seats functioned adequately, it is recommended that they be modified to include leg and arm restraints in order to prevent injuries to these areas.

Brown, T., R. V. Hansen, and A. J. Yorra, "Some Mechanical Tests on the Lumbrosacral Spine with Particular Reference to the Intervertebral Discs, A Preliminary Report," J. Bone Joint Surg. (Amer.), 39-A(5):1135-1164, October 1957.

ABSTRACT: The investigations reported here represent an effort to explore the possiblities of obtaining quantitative data on the mechanical properties of the lumbosacral spine by applying to fresh autopsy specimens of the spine testing techniques used in civil or mechanical engineering. Few tests have been made and the data are insufficient. However, the findings to date are of interest and encourage us to continue these investigations.

With the exception of the markedly osteoporotic spines which failed at relatively low axial loads, the ultimate axial compressive load for the lumbar discs tested ranged from 1,000 to 1,300 pounds. Stiffness values for these discs ranged from 470 to 8,250 pounds per inch initially but increased to 12,000 to 20,000 pounds per inch after the applied load reached 200 to 400 pounds. Failure under axial compression took place in the vertebral end-plates even when well developed ruptures of the annulus were present. Failure of the plate ranged from imperceptible cracks to more or less complete collapse of the end-plate depending on the condition of the bone (presence or absence of osteoporosis) and on the size of the load applied.

Under the experimental conditions employed here, which involved a gradually increasing load over periods ranging from ten to thirty minutes, the volumes of five discs decreased under axial compression by from 1.0 to 2.5 cubic centimeters before failure occurred due to fracture of one of the vertebral end-plates and collapse of the underlying vertebral body. This decrease in volume is thought to be due both to collapse of the fissures and spaces ordinarily present within all adult discs and to the passage of fluid across the vertebral end-plates into the medullary spaces of the adjacent vertebral bodies.

Tests of the tensile strength of various portions of two intervertebral discs revealed that the tensile strength ranged from 0 to 700 pounds per square inch. In general, the weakest areas in both discs were the central and lateral portions. The tensile strength of three specimens of ligamentum flavum ranged from 226 to 373 pounds per square inch.

Two discs (the fourth lumbar) were subjected to combined axial loading and bending while the expansion and contraction of the discs were recorded at various points about the circumference of the annulus. During bending the discs expanded on the concave side and contracted on the convex side of the curve, while at points located at 90 degrees to the plane of motion little or no expansion or contraction occurred. The only exceptions to this general pattern of behavior were in the posterolateral portions of the discs, where annular ruptures are most frequently

found. The greatest expansion and contraction occurred on the anterior aspect of these discs during straight flexion and extension.

One fatigue test was performed in which cyclic bending and compression stresses were imposed on a single disc. For technical reasons the test was not satisfactory. It is of interest, however, that rapid failure of the annulus occurred under the conditions of this experiment characterized by a horizontal tear of all but the most peripheral fibers of the annulus. The resulting picture was not unlike that seen in some extensively degenerated discs.

The findings of particular interest in the work presented here are as follows:
1. Under axial compressive stress, failure of the disc complex invariably took place in the cartilaginous plate. In the few specimens tested the type of failure varied according to the condition of the bone rather than according to the condition of the disc. In the spines from younger individuals small cracks occurred, while in the old spines with osteoporosis, there was more or less total collapse of the plate. The similarity of the small cracks produced in these specimens to those found in the autopsy material studied by Beadle and by Coventry, Ghormley, and Kernohan was quite striking. Many have been inclined to assume that these defects were of little clinical significance due to their small size. However, the findings presented here suggest that such an assumption may not be valid. Failures of the end-plate may play a role in the causation of pain in some back injuries when the roentgenograms show no abnormality. In fact, Hirsch reported one case in which failure of the plate was demonstrated in a man in whom sudden low-back pain developed after a strenuous effort to right an overturned car. However, the special technique to tomography was required to visualize the defect. The relief of back pain resulting from the intradiscal injection of a local anaesthetic or the anti-inflammatory hormone, hydrocortisone, might be explained by this mechanism also.

2. In these tests failure of the annulus fibrosus occurred only as the result of extremely rapid cyclic bending combined with mild axial compression. However, no protrusion of disc material was produced in this short period but rather a linear horizontal tear through all but the most peripheral fibers which still remain intact. In the one specimen in which failure was induced by flexion, the inferior posterior margin or the superior vertebra was avulsed, but the annulus remained intact.

3. It is commonly stated that the nucleus pulposus is the structure by which stresses are distributed uniformly to the annulus fibrosus and cartilaginous plates. It is furthermore stated in the literature that the nucleus pulposus moves toward the convex side of the curve when the spine bends to either side or forward and backward. The behavior of the two specimens subjected to combined axial loading and bending in this investigation did not seem consistent with this concept. The annulus invariably bulged on the concave side apparently as the result of compression between the opposing vertebral surfaces. The thickest and strongest portion of the annulus, that is its anterior third, bulged the most.

This would be more consistent with direct compression of the annulus than with bulging caused by deformation of the nucleus pulposus or displacement of the nucleus toward the opposite side. If there were a significant amount of displacement of the nucleus toward the convex side, it would not be anticipated that the annulus would retract on this side, as was observed in these specimens. Therefore during bending the annulus in these rather aged discs would appear to be subjected primarily to direct compression rather than to hoop tension as would be the case if its only function were to resist deformation of the nucleus pulposus. Friberg, as the result of his studies of fresh specimens of the spine, also concluded that the annulus had a weight-bearing function.

This behavior of the disc may well vary with age. The more fluid nucleus of the child may displace more during bending than the relatively fibrotic and fragmented nucleus of the adult.

4. Under axial compressive loads the volume losses of the intervertebral discs before failure in the four specimens tested were 1.0, 1.5, 2.5, and 2.5 cubic centimeters, respectively, during time intervals ranging from ten to thirty minutes. Previous clinical observations on the disappearance of water-soluble radiopaque solutions after injection into the disc space have suggested that fluid transfer across the cartilaginous plates occurs quite rapidly during life even in the recumbent position when compression forces are minimal. It remains to be determined how such factors as age and degeneration of the cartilaginous plates effect the rate and amount of this transfer. Degenerative changes which occur within the disc with advancing age may be related in some way to alterations in this fluid transfer.

The experimental methods reported here are thought to show sufficient promise to warrant a more extensive testing program on specimens from different age groups and in sufficient numbers to obtain data of statistical significance.

Furthermore, other tests would be desirable. For instance, impact tests might furnish quantitative data on the mechanism of injuries associated with falls and other sudden movements. The effect of other types of stress including shear and axial torsion would also be of interest.

30

Chaffee, J. W., "Change in Human Center of Gravity Produced by Change in Direction of Acceleration," ARS Journal, 1677-1680, November 1962.

ABSTRACT: The two-dimensional location of the center of gravity of the seated human body was studied on 25 male subjects under conditions of experimentally controlled changes in the angle at which a 1-g acceleration acted upon the completely restrained body. It was found that varying the direction of the simulated acceleration vector from 15° through 80°, measured from the torso axis forward, produced: 1) a migration of the group average center of gravity along a curved path of 2.15-in. arc length; and 2) a consistent rotation of the axis of maximum individual variability (supposed "optimum" thrust vector) from 10^{o} 53' aft of the torso axis to a maximum forward angle of 90^{o} 16'. Speculation concerning the practical applications of these findings to the design of rocket-powered systems (e.g., escape capsules) is presented.

31

Charles, J. F., "Fractured Vertebrae in U. S. Navy Aircraft Accidents," J. Aviation Med., 24:483-490, December 1953.

ABSTRACT: The fractured vertebrae sustained in U. S. Navy aircraft accidents involving pilots only were reviewed over the five year period from January, 1948. The causal factor in fractures other than compression fractures of the lumbar and thoracic was clear. Transverse process fractures generally followed violent swerving or cartwheeling during a forced landing. Cervical fractures of all types most frequently involved nose overs followed by acute flexion of the neck. The majority of cases were compression fractures of the lower thoracic and upper lumbar vertebrae. In general the aircraft either stalled or mushed into the ground or struck an embankment in a nose-high altitude during the initial part of the slide. The evidence appears to indicate that vertical forces acting through the seat bottom rather than acute flexion of the spinal column are causing the compression fractures of the thoracic and lumbar vertebrae.

32

Christ, W., and H. Dupuis, The Influence of Vertical Oscillations on the Vertebral Column and Stomach, AMD-TT-64-1, Aerospace Medical Division, Brooks Air Force Base, Texas, 1964.

ABSTRACT: A limited sitting area in vehicles burdens the vertebral column and the stomach to a considerable extent. Drivers and passengers on farm tractors and other self-propelled construction machinery are especially affected. Extensive technical measurements (Dupois, Broicher, Drechsler) revealed the nature and extent of the forces acting upon man. A statistical analysis of a considerable number of young farm workers (Christ) revealed among 50% of them a growth and structure disturbance of the vertebral column. A premature incapacitation can be expected in each case when there is insufficient resistance ability to meet the stress. All functional studies up to 1960 depended on external observations of the body and gave indirect conclusions about the attitude of the vertebral column. Observation of the stomach was completely impossible. Since 1961 we had at our disposal a "Cinelix"-image amplifier, manufactured by Siemens-Reiniger-Werke Erlangen, and an X-ray movie arrangement. Since we had high image magnification and a large image picture we could observe and film the larger sections of the spinal column and the whole stomach.

EXPERIMENT ARRANGEMENTS

1. Vibration Stand. The vibrations of the actual vehicle were simulated in the X-ray institute because the X-ray equipment due to its extended medical use and its fixed installation could not be taken to the movable attachment stand of the tractor.

This required construction of a scaled down stand which would produce vibrations like those occurring on tractor seats. Extreme conditions of vibration loads could not be simulated due to technical limitations in photo recording.

The vibration stand was constructed by the Max Plank Institute, in their own work shop and according to their own design (figure 1).

33

Christy, R. L., "A Survey of Present Techniques for Emergency Escape from Aircraft," *Physics and Medicine of the Upper Atmosphere, A Study of the Aeropause,* University of New Mexico Press, Albuquerque, N. M., 509-515, 1952.

ABSTRACT: The advantages and drawbacks of the following escape techniques are discussed: (1) ordinary bailout over the side of the airplane: (2) the escape chute, in which the pilot drops backward and downward; (3) the ejection seat, propelled by an explosive charge with sufficient upward velocity to clear the vertical stabilizer (two types are in use: one in which the seat is fired by the pilot reaching up and pulling a curtain down over his head and face, and the other fired by controls placed near the legs of the pilot); and (4) the ejectable cockpit capsule. Further studies are in progress on deceleration tracks, catapults, and human centrifuges to determine man's tolerance for acceleration and deceleration under various conditions.

34

Christy, R. L., Jr., "The Navy Program for Aircraft Escape," *J. Aviation Med.*, 22(5):408-417, October 1951.

ABSTRACT: Conventional bailout will be used for low-speed escape, although it is believed that an ejection seat should be strongly considered where feasible for all one-place and two-place training and operational aircraft. The escape chute has particular value in relatively high performance two-place fighter and attack aircraft. Finally, the ejectable cockpit is considered to be the preferred method for the very high-speed, high-altitude fighter aircraft.

35

Chubb, R. M., W. R. Detrick, R. H. Shannon, "Compression Fractures of the Spine During USAF Ejections," Aerospace Med. 36(2):140, (Abstract) February 1965

ABSTRACT: All ejections from United States Air Force aircraft from 1 January 1960 through 31 December 1964 were reviewed in order to determine the causes for compression fractures of the spine. The variables considered included the type aircraft and ejection seat; body position at the time of ejection; age, height, and weight of the crew member; and the various configurations of parachutes, survival kits, cushions, and other personal equipment.

Preliminary investigations revealed that a higher percentage of ejectees had compression fractures during ejections over water than during ejections over land. In addition, it was learned that the Air Training Command experienced very few compression fractures. These two statistics stimulated this more detailed investigation of the variables that probably produced the noted differences.

36

Chubb, R. M., W. H. Davidson, and W. D. Gable, "The Pathology of Ejection Failure," Aerospace Med., 34(11):1050-1054, November 1963.

ABSTRACT: A review of all fatalities accessioned since 1957 at the Armed Forces Institute of Pathology as a result of ejection failures has been completed. The circumstances surrounding death and the autopsy findings, both anatomical and toxicological, have been studied in an effort to determine the causes of fatal injuries. The results of this study are presented in order to point out the patterns of injury seen in the different ejection situations. Representative cases are briefly presented in order to show the mechanism of injury and thus form a basis for recommendations for prevention of these injuries.

37

Chunn, S. P., and R. H. Shannon, "USAF Rocket Ejection Experience," Life Sciences Group, Directorate of Aerospace Safety, Norton Air Force Base, Calif., 1964.

ABSTRACT: In summary, rocket assisted ejections are increasing in significant numbers. This increase is synonymous with a general reduction in the overall success of ejection (ballistic and rocket) escape. The decline in the success rate is a matter of great concern to safety people; however, the reasons are becoming more and more apparent as the experience level increases. This at least gives us, as well as R&D, something tangible upon which to implement corrective action. Some of the more obvious conclusions at this time are: (1) In order to realize the full effectiveness of rocket catapults and achieve a zero altitude zero

airspeed ejection capability, the slow deployment characteristics of existing personnel parachutes must be eliminated. (2) A requirement exists for an improved means of seat separation. (3) It is highly probable that crewmembers are delaying ejection because of undue confidence in the advertised capabilities of rocket ejection systems. (4) In some cases, system complexity has resulted in a compromise in reliability and the low level capability. (5) Although the success rate is lower, lives are being saved by rocket ejection systems that would not have been saved with ballistic systems. These conclusions dictate a need for immediate and continuing escape system refinement by R&D and for additional aircrew guidance regarding the use of these systems at all appropriate levels.

38

Clark C., Acceleration and Body Distortion, Rept. ER 12138, The Martin Co., Baltimore, Md., 1961

ABSTRACT: The author urges the point of view that tolerance to acceleration depends more on the extent of body distortion as a consequence of the interaction of the reactive forces due to the acceleration and the opposing forces due to tissue displacements and to the restraint system than on the reactive force due to acceleration alone.

es 39

Clarke, N. P., and C. R. Feeley, "Aeromedical Aspects of the B-58 Capsule Ejection Seat," presented at 33rd Annual Meeting of the Aerospace Medical Association, Atlantic City, N. J., April 1962.

ly

ABSTRACT: The evolution of aircraft escape devices from the open ejection seat into the encapsulated seat system brought many critical and crucial human factor problems. Paramount of these problems was in the area of biodynamics, in which the establishment of the additional human tolerance data was required for making man compatible with this new concept of escape. This paper presents the aeromedical support provided to the B-58 escape capsule program under the leadership of the Aerospace Medical Laboratory, Wright-Patterson AFB. Details of the tests conducted and the highlights of the related biodynamic factors will be discussed. The critical portions of the animal and human testing conducted by the contractor and the Air Force to validate the design principles and establish command confidence in this new escape concept will be discussed.

40

Code, C. F., M. D. Williams, E. J. Baldes, and R. K. Ghormley, "Are the Intervertebral Disks Displaced During Positive Acceleration?", J. Aviation Med., 18:231-236, 296, June 1947.

ABSTRACT: Anteroposterior and lateral roentgenograms were made of the lower part of the spinal columns of four subjects before and during positive accelerations of 2 to 6 g.

Measurements were made of the lumbar intervertebral spaces and of the length of the lumbar part of the spinal column. No significant changes in these measurements were observed during the accelerations tested. It is concluded that in these normal subjects there was no compression or displacement of the intervertebral disks.

41

Cofer, F. S., H. M. Sweeney, and C. E. Frenier, Escape from High Speed Aircraft, Eng. Div. Memo Report TSEAC11-45341-1-2, Engineering Division, Air Materiel Command, Army Air Forces, ASTIA ATI 9213, 9 August 1946.

ABSTRACT: This publication presents the history, current progress, and future plans for escape from high speed aircraft. A summary of the accomplishments of the Air Materiel Command in connection with escape from high speed aircraft is contained in the following Appendices: Appendix 1 outlines the work of the Aircraft Laboratory; Appendix 2 outlines the work of the Aero-Medical Laboratory; Appendix 3 outlines the work of the Personal Equipment Laboratory; Appendix 4 is a bibliography on this subject. The contents of the Appendices of this report provide an introduction to the problems of escape from high speed aircraft for all concerned The necessity for safe escape from high speed aircraft requires an immediate solution as well as long range research.

42

Cooper, K. H., and F. M. G. Holmstrom, "Injuries During Ejection Seat Training," Aerospace Med., 34(2): 139-141, February 1963.

ABSTRACT: The USAF ejection seat trainer used for emergency escape familiarization is an occasional cause of injury to trainees. Injuries that occur are usually minor and related to high headward acceleration of very short duration. Three new cases of coccygeal injury resulting from ejection seat training are reported. The character and magnitude of the accelerative forces, the role of body position, and the protective value of high energy absorbent seat cushions are discussed. Recommendations to minimize the recurrence of such injuries are included.

43

Cumming, F. G., "Escape from Aircraft at High Speeds and Low Altitudes," Escape and Survival: Clinical and Biological Problems in Aerospace Medicine, Pergamon Press, New York, N. Y., AGARDograph 52, 5-9, ASTIA AD 261 881, 1961.

ABSTRACT: An account of the recent experimental research conducted on evacuation at low altitudes and the present state of this question are discussed.

The problem of the opening of the parachute at high speeds constitutes a fundamental difficulty at speeds inferior to 600 miles per hour. The questions relative to physical protection against "slap" (air blast) and the forces of abrupt deceleration are studied at speeds up to 800 miles per hour.

44

Davies, J., The Problem of Back Fractures During Ejection from USAF Aircraft. Period: 1 August 1949 thru 31 March 1956, Publication 2-57, AFR 190-16, Norton Air Force Base, Calif., January 1957.

ABSTRACT: This study concerns the frequency and causes of back fractures which were experienced during ejection escape from USAF aircraft.

A review of ejection escape experience from USAF aircraft for the period 1 August 1949 through 31 March 1956 revealed that 5% (32) of all nonfatal ejections involved back fractures. Fourteen personnel believed their fractures occurred during firing of the seat, 7 on landing, 2 when the chute opened, 2 on contact with the canopy, and 7 at unknown or indefinite times. Three of the latter 7 were reported as possibly occurring when the seat fired.

The major cause of fractures occurring when the seat fired was poor body position. Poor body position during ejection was a result of: undesirable aircraft attitude, lack of effort or time to prepare for ejection, inability to use the headrest, and leaning forward to look at or reach the ejection trigger.

Fractures during firing of the ejection seat have occurred only in F-86, F-84, F-94, T-33 and B-52 aircraft. These facts indicate a need for further investigation of the role ejection seat configuration, filler blocks and survival kits play in causing or preventing back fractures during ejection.

Present available data does not indite any particular aircraft type or model as being particularly hazardous with regard to back fractures during ejection.

The incidence of back fractures during ejection escape can be reduced by:

1. Greater training emphasis on:

   a. The necessity for proper ejection position.
   b. The use of proper equipment in the seat.
   c. Correct parachute fitting, opening and landing techniques.

2. Additional research and improved design with regard to seat configuration and equipment used in the seat.

3. Publishing more explicit instructions on equipment which should and should not be used in the seat.

45

DeCilia, F., and P. Italiano, "Some Considerations Concerning Spinal Injuries Caused by Flight Accidents (Alcune Considerazioni sulle lesioni traumatiche vertebrali da incidente di volo)," Riv. Med. Aero. (Rome), 20(2): 262-268, April-June 1957.

ABSTRACT: Four cases are reported of spinal lesions in pilots which occurred during ejection-seat bailout, or during emergency landing. Since these lesions have a poor symptomatology, it is necessary to x-ray the lumbar portion of the spinal column, especially the dorso-lumbar tract (accounting for three-fourths of all spinal injuries), of all pilots involved in all types of flight accidents.

46

DeHaven, H., B. Tourin, and S. Macri, "Aircraft Safety Belts: Their Injury Effect on the Human Body," Crash Injury Research, Cornell University Medical College, New York, N. Y., ASTIA AD 14 643, July 1953.

ABSTRACT: An examination was made of the injuries sustained by 1039 survivors of 670 lightplane crashes. Chi-square methods were employed in statistical analyses to relate the use of the belt and body injuries of survivors. Safety belts were shown to be an infrequent cause of injury and to serve as effective protection. Severe snubbing action of safety belts as seen in 80 cases showed no significant correlation with the occurrence of intra-abdominal and lumbar spine injuries. Critical intra-abdominal and lumbar spine injuries appeared related to each other and to vertically acting forces. Bruises and minor contusions were attributable to safety belts. Injuries which occurred without any signs of snubbing were jolt loads transmitted by supporting structures and seats. Injuries of the upper and lower torso were associated with and increased by failure of safety belt installations. The percentage of all trunk injuries sustained by users and nonusers of safety belts was similar. No increased frequency was observed in injuries to the torso, neck and spine by the use of the belt Survivors not using safety belts suffered more serious injury than those that used them. Upper and lower torso injuries were also related to failure of belt installations. Dangerous-to-life injuries of head and body were associated and increased with vertical crash forces.

47

Dempsey, C. A., "Human Protection in Abrupt Acceleration Environments," presented at the Institute of Environmental Sciences National Meeting, Washington, D. C., April 1961.

ABSTRACT: The accelerations encountered in space flight are divided into three distinct segments: vibration, abrupt acceleration and long term acceleration. When these forces are acting as an integrated function they produce a singular subjective experience to the individual. The various maneuvers of manned space flight which produce abrupt accelerations are soft surface landings, emergency escape, air deceleration and hard surface landings. In addition, the potential hazard of explosion is significantly increased in space vehicles and forms another major source of high transient accelerations.

The human body can be categorized as a complex combination of systems which respond to the abrupt acceleration forces in accordance with the laws of a viscous elastic system under the action of a constant unbalanced force or harmonic motion. While the body might at first appear to act as an integrated whole; it in reality, is segmented into four different parts which respond individually to the force and then in turn transmit their response to the other segments. These individual segments are: dorsal cavity, thoracic cavity, pelvic cavity, and body extremities. Vital body organs can sustain high transient accelerations when the force vector is oriented in the proper direction and the body is completely supported throughout the load period. Present research efforts are dedicated to the premise of completely understanding the protective requirements which are necessary to sustain the astronauts during abrupt acceleration conditions in all areas of aerospace operations.

48

DeHaven, H., "Mechanical Analysis of Survival in Falls from Heights of 50 to 150 Feet," War Medicine, 2(1): 586-596, July 1942.

49

"Developing the Martin-Baker Ejection Seat," The Aeroplane, 90(2324): 141-143, and 168-171, 10 February 1956.

50

"Douglas Designs Compact Lightweight Ejection Seat," Aviation Age, 23(3): 50-53, March 1955.

ABSTRACT: A new ejection seat has been designed for the A4D-1, which possesses a carrying skin. During ejection, the chair is automatically loosened from the pilot. He possesses no adjustable head or foot rest. The chair and the equipment of the pilot weighs over 50 lbs. less than the comparable installation of the Douglas A2D-1 and F4D1 manufactured for 25 g force and a 40 g crash force. It withstood a load of 60 g.

51

Ducros, E., and R. Gregoire, "Injuries in Jet Flying (Traumatologie dans l'aviation a reaction)," Rev. Med. Aero. (Paris), 9(3): 213-222, 1954.

ABSTRACT: The records of 245 jet plane accidents that occurred in France from 1950 to 1953 were analyzed from a medical and statistical point of view. On the basis of this analysis the following conclusions are drawn: (1) the ratio of deaths to non-fatal injury was nearly 4 to 1. (2) 75% of the deaths were caused by far-reaching body mutilations due to explosion or fire, often leading to complete disintegration. (3) The number of the wounded was extremely low (6 per 100 accidents; and the injuries relatively light. (4) Among the wounded no head injury was reported. The most affected part of the body was the dorso-lumbar region. Although the safety harnesses prevented the pilot from being catapulted against the wall, they did offer no protection against injury of the vertebral column. (5) The necessity is apparent to search for supplementary protective devices, which on the one hand should be more flexible, on the other more shock-absorbent, and also allow the pilot to adjust his position so as to minimize vertebral injuries.

52

Ducros, E., and R. Gregoire, "Spine Injuries in Flight Accidents of the French Air Force (Atteintes vertebrales dans les accidents aeriens, armee de l'air)," Rev. Med. Aero. (Paris), 9(4): 483-487, 1954.

ABSTRACT: The statistical data of the French Air Force for the years 1950 to 1953 show that vertebral lesions were found in 42.5% of the fatal injuries and 11.5% of the non-fatal injuries. A breakdown of these statistics is presented according to the type of injuries and the type of airplane and descriptions are given of 13 cases of injured fliers exemplifying the most common involvements of the backbone.

53

Dugan, J. C., Method for Calculating the Trajectory of a Man Ejected from an Airplane, Memo Ser. TSEAC3-45341, USAF Project MX-792, Engr. Division, Air Material Command, ASTIA ATI 52657, July 1946.

ABSTRACT: Formulas are presented for computing the trajectory of a man and seat ejected from an airplane. Results of low speed flight tests show that the drag coefficient is approximately 1.33. For high speeds the percentage increase in drag coefficient is assumed to be the same as that for a sphere. Sample trajectories of a man and seat weighing 300 lbs. have been computed for several airplane speeds and altitudes. It is concluded that the presented method of calculating the trajectory of a man and seat ejected from an airplane can be used with satisfactory results.

54

<u>Dyna-Soar Ejection Seat and Survival System</u>, Rept. No. 10-81000, Boeing Company, Seattle, Washington, ASTIA AD 269 506L, 15 September 1961.

ABSTRACT: The design, fabrication, performance, and testing requirements for a type of equipment designated Ejection Seat and Survival System is reported. It is designed for pilot escape and survival from the Dyna-Soar glider in instances when a satisfactory landing site cannot be reached or when other conditions made an attempted glider landing impractical.

55

<u>Dyna-Soar Ejection Seat and Survival System</u>, Contract AF 33(657)-7132, Boeing Company, Seattle, Washington, ASTIA AD 282 004L, 1962.

ABSTRACT: Military requirements, specifications, and design are given for the Dyna-Soar ejection seat and survival system.

56

Eiband, A. M., <u>Human Tolerance to Rapidly Applied Accelerations: a Summary of the Literature</u>, NASA Memo 5-19-59E, Lewis Research Center, Cleveland, Ohio.

57

"Ejection Equipment for Mach 3," <u>Flight</u> (London), 70(2497):856, 30 Nov. 1956.

ABSTRACT: An ejection seat designed by Lockheed Aircraft for downward ejections at speeds up to Mach 3 features: (1) brackets to hold the pilot's helmet steady and to reduce loads on the neck; (2) knee guards to prevent splaying of the legs, with a webbing harness to restrain the arms; (3) automatic straps to prevent flailing of the legs; (4) fins extending beneath and beside the seat to provide stabilization; and (5) an airflow deflector plate forming an "atmosphere capsule" to reduce transverse forces and air blast.

58

<u>Ejection Seat, Canopy and Oxygen Equipment Problems. Period 1 January 1951 thru 30 June 1953</u>, Publication No. 33-53, Directorate of Flight Research, Norton Air Force Base, Calif., ASTIA AD 38 234, 26 October 1953.

ABSTRACT: This 548 page volume contains the following tabulated data:

Tab. A - Aircraft Canopy Failures and Difficulties - Jet Fighter & Jet Bomber Aircraft

Tab. B - Ejection Seat Failures with Subsequent Action Taken & Injury to Personnel

Tab. C - Canopy Accident Briefs

Tab. D - Ejection Seat Accident Briefs

Tab. E - Briefs of Unstaisfactory Reports on Canopies

Tab. F - Briefs of Unstaisfactory Reports on Ejection Seats

Tab. G - Maintenance Analysis of Ejection Seats & Canopies

Tab. H - Engineering Data on Ejection Seat & Canopy Installations

Tab. I - Firing of the Ejection Seat from Aircraft on Ground or from Ground Impact

Tab. J - Briefs of Unsatisfactory Reports on Oxygen Equipment

Tab. K - Briefs on Major Aircraft Accidents in which Hypoxia was a Stated or Probable Cause Factor

Tab. L - Distribution List

59

"Ejection Seat Developed for Mach 3 After ARDC Decides on Capsules," Aviation Week, 65(15):72, October 1956.

ABSTRACT: A supersonic escape ejection seat has been developed which is designed to permit safe escape limits exceeding 800 kts. at sea level and Mach 3 at altitude. The development comes in the face of a decision by Air Research and Development Command to require escape capsules incorporating protective and survival devices for all new aircraft with performance exceeding 600 knots IAS and 50,000 foot altitude.

60

"Ejection Seat Development in Sweden," The Aeroplane, 85(2209): 692-694, 20 Nov. 1953.

ABSTRACT: Some information is given about the ejector seats developed by S. A. A. B. in Sweden.

The first dummy ejection was made by S. A. A. B as early as January, 1942 to test their model I ejection seat. A description of this seat is given in the article The Mark II is a special light weight seat (installed weight 70 lb.) which is intended for installation in the Folland Gnat.

The ejection velocities are considerable lower than the British equivalents. A drawing with installation dimensions is given.

61

Ejection Seat Study, A Report of Ejections and Bailouts for Aug 1949—May 1959, Naval Aviation Safety Center, Norfolk, Va., ASTIA AD 125052.

ABSTRACT: The increasing ejection rate per unit hours flown and an increasing number of these units flown indicated a steady mounting of the frequency of ejections. There is a pronounced relationship between successful ejections and altitude. The relationship between altitude and successful ejection becomes apparent at 5000 ft. and ejections become increasingly hazardous as the altitude decreases below this height. The mean altitude at which ejections occur did not increase during the period covered by this study. In terms of mach number, M = 0.70 is the beginning of the critically dangerous zone for ejections. Ejecting from the F9F, F7U, and TV model aircraft is significantly more dangerous than ejecting from the F2H and FJ models. Ejections from the swept-wing F9F are no more dangerous than those from the straight wing F9F. Ejections are more dangerous than bailouts with present equipment. No relationship existed between altitude and in injury in bailouts (as long as irreducible minimum is observed). Successful bailouts may be made at lower altitudes than ejections with present equipment. No relationship existed between speed and injuries resulting from bailouts within the speed range in which bailouts are made. The mean speed at which bailouts are made is substantially slower than the mean speed at which ejections are made. Bailing out from the F4U model aircraft is significantly more dangerous than bailing out of AD and SNJ models.

62

Ejection Seat Study for Calendar 1959, Naval Aviation Safety Center, Norfolk, Va., ASTIA AD 238 492, June 1960.

ABSTRACT: A statistical analysis is presented showing the degree of personnel injuries sustained during ejection from disabled aircraft. Factors analyzed include altitude, speed, seat systems, attitude, and types of emergency. Ejection frequency and fatality rates per 10,000 hours flying time are also presented. A comparison is made between injuries resulting from ejections and bailouts.

63

Ellis, J. D., "Compression Fractures of the Vertebral Bodies and Other Changes Mistaken for Them," J. Bone Joint Surg. (Amer.), 26(1):139-145, 1944.

64

Elward, J., "Motion in the Vertebral Column," Amer. J. Roentgen., 42:91-99, 1939.

65

Emergency Airborne Escape Summary. A Report of Ejections and Bailouts for Calendar 1960, Naval Aviation Safety Center, Norfolk, Va., ASTIA AD 259 078.

ABSTRACT: This summary presents an analysis of emergency airborne escapes occurring during the calendar year 1960. Its purpose is to apprise operators, commands and others of the record of escape system usage as utilized in Naval aircraft.

66

"Emergency Exit," Aeronautics (London), 31:94, 95, 97, and 98, 1949.

ABSTRACT: The article deals with the emergency equipment introduced in the early days and with the mechanism of the Martin-Baker ejection seat. Live ejections made at high speed with the Martin-Baker ejection seat between 24-7-1946 and 17-7-1948 are tabulated.

67

Evans, F. G., Lissner, and L. M. Patrick, "Acceleration - Induced Strains in the Intact Vertebral Column," J. Appl. Physiol., 17(3), May 1962.

ABSTRACT: Results of more than 170 tests with the embalmed bodies of a 69-year-old white male and two Negro males 56 and [illegible]2 years of age which were subjected to a maximum acceleration of 20 g revealed an approximately linear relation between acceleration and strain in the sacral ala and lumbar vertebrae. This relationship was less linear for the thoracic and cervical vertebrae. The magnitude of compressive strain in the anterior aspect of the body of C_3 and L_3 is a function of the degree of freedom of movement of the head and thorax. The strain in C_3 is progressively increased by increasing freedom of movement of the head and thorax but the opposite effect occurs in L_3. The anterior aspect of the body of C_3 is subjected to compressive strain in the normal position of the head but extension of the head changes the strain to tension. Seating the cadaver on a polyurethane cushion 4 in. thick increased the peak strain in the vertebral column. No vertebral fractures or dislocations demonstrable by X rays have been produced by maximum accelerations of 20 g. End-plate fractures of 28 fresh vertebrae were produced by an average load of 672 lb. (435-900 lb.) statically applied in a materials-testing machine.

68

Evans, F. G., and H. R. Lissner, "Biomechanical Studies on the Lumbar Spine and Pelvis," J. Bone Joint Surg. (Amer.), 41A(2):278-290, March 1959.

ABSTRACT: 1. Eleven pelves and lumbar spines (eight embalmed and three unembalmed) were tested under static vertical loading; five specimens of the sacrum and the lumbar spines and five to eight thoracic vertebrae and discs (two embalmed, three unembalmed) were tested by static anterior bending; and four specimens of the sacrum and lumbar vertebrae and discs (all embalmed) were tested by static lateral bending.

2. Embalming increased the average maximum load and energy absorbed during vertical loading but decreased the magnitude of the average deflection.

3. Specimens tested by anterior bending had a greater bending moment, regardless of the condition of the specimen (embalmed or unembalmed) than those tested by lateral bending.

4. Embalmed specimens tested by lateral bending had a greater average deflection than similar specimens tested by anterior bending.

5. The greatest average amount of energy (inch pounds) was absorbed during vertical loading and the least during lateral bending. Embalming increases the energy-absorbing capacity of the pelvis and lumbar spine during vertical loading.

6. Unembalmed specimens tested by anterior bending showed the greatest average deflection.

7. Among the embalmed specimens the load increased more rapidly than the deflection in most of the specimens tested by vertical loading and in all of the specimens tested by anterior bending. In embalmed specimens tested by lateral bending the load increased more rapidly than deflection at first but later leveled off.

8. The slope of the load-deflection curve was generally steeper for specimens tested by vertical loading than for those tested by anterior or lateral bending. The slope of the curves for embalmed specimens was usually steeper than those for unembalmed ones.

9. No apparent relationship was found between the age of the individual whose spine was tested and the various biomechanical phenomena studied.

69

Evans, F. G., H. R. Lissner, and H. E. Pedersen, "Deformation Studies of the Femur Under Dynamic Vertical Loading," <u>Anat. Rec.</u>, 101:225-241, 1948.

ABSTRACT: 1. "Stresscoat" tests of 14 adult male femora under dynamic vertical loading produced deformation patterns on the superior aspect of the neck and the anterolateral (convex) aspect of the proximal and middle thirds of the shaft.

2. The deformation patterns consisted of cracks in the "stresscoat" lacquer.

3. The cracks arise from tension stress in the underlying bone and lie transverse to the direction of tension.

4. The diameter of the neck and of the shaft, as well as the curvature of the latter, influence the bone's degree of bending and the extent of the pattern, so that it is more concentrated in the middle of the bones with a relatively great curvature.

5. The location of the patterns obtained by dynamic vertical loading is essentially similar to those seen in static vertical loading. In both types of tests it is seen that the superior aspect of the neck and the anterolateral (convex) aspect of the shaft are under tension stress while the opposite aspects of the bone are under compression stress.

6. The tests clearly demonstrate that a relatively small load, 15.8 inch pounds of energy, dynamically applied can produce similar deformation patterns in the same same parts of the femur as do loads of 400-715 pounds statically applied.

70

Evans, F. G., and L. M. Patrick, "Impact Damage to Internal Organs," Impact Acceleration Stress, Publication No. 977, 159-172, National Academy of Sciences, National Research Council, 1962.

71

Evans, F. G., "Methods of Studying the Biomechanical Significance of Bone Form," Amer. J. Physical Anthropology, 11:413-435, 1953.

ABSTRACT: Many of the techniques employed by engineers for stress-strain analysis in engineering structures and materials are also applicable for studying similar phenomenon in bones. By these means one may study the stresses and strains produced in bones under controlled conditions of loading and orientation in which the magnitude of the load or the energy applied to the bone, as well as its point of application and direction, can be controlled. It is thus possible to obtain some idea of the behavior of the bone as a mechanical structure or unit. It is, of course, obvious that the experimental conditions employed in such studies are far more simple than those occurring in the bones of a living animal. In the latter case, stresses and strains to which the bone is subjected are constantly changing during different phases of locomotion or movement. It has also recently been shown by Coolbaugh ('52) that a reduction in the blood supply to a bone has marked effects on its physical properties and hence its mechanical behavior.

Regional differences in the physical properties of the human femur have been studied by Evans and Lebow ('51) who found that the areas subjected to tensile strain, as revealed by "Stresscoat" studies of the femur under static and dynamic vertical loading, also have the highest average tensile strength. More recently the same authors ('52) have shown considerable differences in the physical properties of the various bones of the inferior extremities in a single individual. All these factors, as well as age, sex, state of health, and nutrition influence the biomechanical behavior of bones.

72

Evans, F. G., Stress and Strain in Bones, Their Relation to Fractures and Osteogenesis, Charles C. Thomas, Springfield, Ill., 1957.

ABSTRACT: The experiments on the intervertebral discs clearly demonstrated that the discs are very well adapted for withstanding the compressive stresses and strains to which they are normally subjected in the living body. Thus, they can statically adjust themselves to various mechanical demands placed upon them. In addition, the studies of Hirsch and Nachemson show that the discs represent a dynamic system whose mass is constantly in motion. Furthermore, very small rapidly applied loads or forces produce oscillations of the disc with movements measurable in tenths of a millimeter. Neither the body nor the discs are ever mechanically in a state of rest. The more frequently forces act on the discs the higher the frequency of their oscillations.

Hirsch and Nachemson believe that disturbances in the histochemical structure of the intervertebral discs are more important in the rupture mechanism than are mechanical forces. However, they concede that oscillations of the frequency and amplitude found in their studies may exert an influence on the biological phenomena arising in the discs. Hirsch's earlier investigation on the mechansim of low back pain indicate that compression of a disc causes the nucleus pulposus to exert pressure on all points of the annulus fibrosus, which is consequently subjected to circular tensile strain. Intervertebral discs are almost entirely compression resisting structures. Bones, however, are frequently subjected to bending action as a result of which they are required to resist tensile and shearing stresses and strains in addition to compression.

Stresscoat studies on the pelvis and mandible show that they also behave like elastic bodies whose deformations can be demonstrated with relatively small loads. As long as their elastic limit is not exceeded they exhibit con lerable power of recovery. The importance of tensile stresses and strains in fractures was further emphasized by stresscoat patterns in experimentally produced pelvic fractures.

73

Evans, F. G., and M. Lebow, "The Strength of Human Compact Bone as Revealed by Engineering Techniques," Amer. J. Surg., 83:327-331, March 1952.

ABSTRACT: 1. The average ultimate tensile strength (lb./in.^{2}) and percentage elongation under tension were determined for 242 specimens of compact bone from the femurs of seven white, adult male cadavers whose age and cause of death were known.

2. All specimens were of a standardized size and were tested by approved engineering technics which are described. Half of the specimens were air dried at room temperature and tested dry while the other half were placed in a physiologic saline solution and tested wet.

3. Drying the specimens increased their average tensile strength (lb./in.^{2}) but reduced their percentage elongation under tension. The percentage elongation under tension is a good index of the energy (in. lb./in.^{3}) absorbed by the specimen up to the time of fracture.

4. The samples tested wet have a greater percentage elongation under tension, and hence greater energy-absorbing capacity, than did the dry samples. This is also evident from the shape of the stress-strain curve which is a straight line to fracture for the dry samples but a curve for the wet specimens.

5. The specimens from the middle third of the femoral shaft had the greatest average tensile strength and energy-absorbing capacity, as indicated by their percentage elongation under tension.

6. The age of the individual seemed to have little influence on the tensile strength and energy-absorbing capacity of the femur.

7. Similar comparative studies on all the long bones of the inferior extremity of three adult male cadavers revealed that the tibia had the greatest average tensile strength (lb./in.^{2}) and the fibula the greatest percentage elongation under tension. The femur was the weakest in these respects.

8. As in the femur the middle third of the tibia and fibula had the greatest average tensile strength (lb./in.^{2}). The middle third of the tibia also had the greatest percentage elongation but in the fibula, and also the femurs of these individuals, the proximal third of the bone had the greatest elongation. These comparative results should be considered as tentative but also indicative of a trend.

9. The values for the physical properties of the wet-tested specimens probably more nearly approximate similar properties in living bone than do those of dry-tested specimens.

10. The significance and implications of the tests are discussed.

74

Evrard, E., "Rescue of Aviators by Means of Ejection Seats (Le Sauvetage des Aviateurs par Siege Ejectable)," Rept. No. ATIC-305111-A, Air Technical Intelligence Center, Wright-Patterson Air Force Base, Ohio, ASTIA AD 140 536, 1957.

ABSTRACT: During a period of five years (1952-1956) fifteen cases, wherein ejection seats were used in the pursuit plane squadron of the Air Force, were recorded. Five ejections ended in the death of the users. Ten cases of ejection saved the pilot's lives. An analysis of the medical aspects of the ejection conditions and their consequences for the aviator may be taken as precious, practical lessons. Effort is made: (1) to describe the circumstances surrounding the ejection where the consequences were fatal, and those where the conditions under which the ejection took place were abnormal. (2) to contemplate the consequences from the study of these cases as far as practical purposes are concerned.

75

Ewing, C. L., Vertebral Fracture in Jet Aircraft Accidents: A Statistical Analysis for the Period 1959 Through 1963 in the U. S. Navy, U. S. Naval School of Aviation Medicine, Pensacola, Fla.

ABSTRACT: Ejections from jet aircraft account for 24 per cent of all jet aircraft accidents, but cause 60 per cent of all vertebral fractures occurring in jet aircraft accidents. The vertebral fracture rate in ejections has doubled during this reporting period, while the rate in collisions with ground and water has remained essentially unchanged.

Utilizing epidemiological methods, an effort was made to determine the causative factors of vertebral fracture during ejection. It was determined that the majority of these injuries occurred in accidents involving only a few aircraft types and that almost all of these occurred during ejection through the canopy.

These data are widely applicable in the design and evaluation of aircraft, ejection seats, and restraint harness.

76

Fabre, J., "Medical Aspect of First 100 Ejections Practiced in France (Aspect Medical des Cent Premieres Ejections Pratiquees en France) Rev. Med. Aero. (Paris)., 14:223, 1959.

77

Fabre, J., "Aspect Medical des Ejections Pratiquees en France sur Differents Types de Sieges Ejectables," Escape and Survival: Clinical and Biological Problems in Aero Space Medicine, Pergamon Press, New York, N. Y., AGARDograph 52, 18-29, ASTIA AD 261 881, 1961.

ABSTRACT: Over a period of 7 years, a wide diversity of ejection seats have been used in France. This study, reviewing 100 ejections, deals with a survey on the influence of altitude and speed, the percentage of fatalities, major and minor injuries, and of cases in which pilots come out unhurt. in relation with the type of seats used and the improvements which have been added. The second part deals with the specific traumatology of the ejection phenomenon, i.e. injuries of the spine. The author emphasizes the drawback of seats using non-telescopic guns, which involve, within too short a time, values of g which are too high and often exceed the tolerance threshold of the spine.

78

Fabre, J. "Vertebral Traumatology Observed in Aviation," (La traumatologie vertebrale observee en aeronautique) Rev. Med. Aero (Paris), 1(3):63-69, March - April 1962.

ABSTRACT: Vertebral pathology is frequently observed in: (1) pilots of conventional aircraft who crash on a landing strip or on unfamiliar terrain; (2) jet pilots who eject by means of a catapult seat; (3) helicopter personnel; and (4) parachutists. Discussion is presented on the frequency and localization of vertebral fractures in these subjects, their pathogenetic mechanisms, X-ray findings, and preventive measures.

79

Fabre, J., and J. M. Balabaud, "Medical Aspects of the Ejections That Took Place on the Mirage III (Aspect Medical des Ejections Survenues sur Mirage III)," Rev. Med. Aero. (Paris), 3:565-569, January-February 1964.

ABSTRACT: The sequence of events which takes place in automatic pilot ejection in Martin Baker AM4 seats is described. The seat has a maximum acceleration of 19 g. Eight specific pilot ejections are cited: six landed intact; one was inappropriately seated and injured; and the single death was attributed to factors other than seat function. Most of the pilots ejected at low speed and at low altitude. In a study of 200 previous ejections, it was determined that the weight of the pilot is not a critical factor in injury. It is concluded that the seat is a safe one for pilot ejection.

80

Fabre, J., and B. Graber, Seat Cushion Role in Acceleration Production on Ejection Seat Catapulting (Role du coussin de siege dans la genese des accelerations lors du catapultage du siege ejectable), Rapport CERMA 904, Paris, 1959.

81

Fabre, J., and Y. Houdas, "Case Report of a Subject Having Undergone a Supersonic Ejection (A propos d'une observation d'une sujet ayant subi une ejection supersonique), " Revue des Corps de Sante des Armees (Paris), 3(2):247-251, April 1962.

ABSTRACT: This the first French case, and the second or third known case, of ejection at supersonic speed (1,000 - 1,100 kilometers/hour) at an altitude of about 12,000 feet, in which the pilot survived. The pilot was comatose upon landing and his parachute torn during opening at high speed. Medical examination revealed left hemiplegia, right facial paralysis, and fracture of the 12th dorsal and 1st lumbar vertebrae. Coma persisted for 8 days; however, good psychomotor recovery followed. The origin of the disorders was attributed primarily to the effects of three factors; (1) blast, (2) deceleration, and (3) rotation of the seat and pilot.

82

Fabre, J., and Y. Houdas, Physiological Determination of Factors Responsible for Severe Lesions at the Time of Supersonic Ejections (Determination Physiologique des Facteurs Responsables des Lesions Graves lors des Ejections Supersoniques), Rev. Med. Aero. (Paris), 2:190-192, December 1961.

83

Farmer, R. A., A. M. Donnell, and J. P. McCann, Air Training Command Ejection Experience, 1 January 1962 to 31 December 1964, Air Training Command, Randolph Air Force Base, Texas.

ABSTRACT: This paper presents a study of the USAF Air Training Command's experience in ejections from disabled jet aircraft. The study encompasses the three-year period of 1 January 1962 to 31 December 1964. During this period, practically all undergraduate pilot training in this command was accomplished in dual-placed jet trainers equipped with ejection seats.

The experience of Air Training Command during this three-year period indicates

that the young, well-trained pilot does very well in the ejection escape situation. The analysis of 46 ejections in 1962 and 1963 reveals a success rate of 84.8 per cent. All ejections initiated above 300 feet terrain clearance were successful.

The major injury rate is a relatively low 12.8 per cent of the 39 successful ejections. There were no vertebral fractures.

Instructor and student pilots of Air Training Command represent the youngest and least experienced of USAF pilots. For 1962 and 1963, 89 per cent of the ejectees were less than 30 years of age, and 76 per cent had flown less than 200 hours in the type of aircraft involved.

These factors of training and experience, along with the factors usually presented in such ejection escape experience analyses, will be presented. This will allow easy comparison of Air Training Command and USAF experience in this important area.

84

Fitzgerald, J. G., M. L. Fisher, and A. J. Barwood, An Experimental System of Pre-Ejection Body Restraint, Report No. FPRC/Memo. 186, Flying Personnel Research Committee, Great Britain, August 1962

ABSTRACT: A pre-ejection body restraint system is described which appears to satisfy most, if not all, of the postulated physical requirements listed in this report. The system has the following advantages: (1) it is simple in concept and safe in operation; (2) it does not delay ejection since it uses a normal manual procedure; (3) full restraint is accomplished in less than 0.4 sec.; (4) spine, shoulders, and head are in good alignment for ejection; (5) individual sizing should not be necessary; (6) the entire system should not weigh more than 20-25 pounds; and (7) with practice, the six connections to the airman's clothing can be made in less than half a minute.

85

"Fitness for Duty," Flight, 59(2192):104-107, 25 January 1951.

ABSTRACT: Survey of the work of the R. A. F. Institute of Aviation Medicine at Farnborough from 1939 till now. On the improvements of ejector-seats, pressure cabins and air-conditioning, g-suits, pressure waistcoats, ventilated suits and other items of specialized clothing.

86

Freeman, H. E., et al., Investigation of a Personnel Restraint System for Advanced Manned Flight Vehicles, AMRL-TDR-62-128, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, Dec. 1962.

ABSTRACT: To develop new concepts for personnel restraint, the following studies were conducted. Characteristic accelerations were defined for advanced manned flight systems. Accelerations of 8 to 12 G which are associated with ballistic reentry, produce the most severe physiological stress. Landing impact, generating low-total-energy accelerations of 60 to 100 G's peak on the capsule, produced the most severe structural loading. Human tolerance to acceleration was studied by a survey of the available test data and a structural analysis of the human body. Test data for high-peak-magnitude low-total-energy acceleration exposures were not reported in the literature on controlled experimentation. Case histories of accidental falls and suicides were studied to gain insight into human tolerance to this type of acceleration. Several basic crew restraint concepts were evolved and evaluated. A concept employing rigid contoured support was selected to limit body-element displacement and distortion and to minimize rebound. A test system was designed and fabricated. Mechanisms were designed to preposition and pretension the crewman mechanically prior to impact. Further research should include thorough testing of the test system to determine the protection achieved by rigid contoured restraint. If high level protection is demonstrated, an operational prototype should be developed.

87

Frost, R. H., "Escape from High-Speed Aircraft," Aeronautical Engr. Review, 14(9):35-45, September 1955.

ABSTRACT: This is a review of German, Swedish, British, and American experimentation with high-speed bail-out. It is concluded that the use of the ejection seat is limited to speeds corresponding to little more than sonic flight at sea level, because the accelerations encountered at higher speeds in the first seconds after ejection approach human limitations (detailed data are given). Secondarily, there would be problems in retaining protective equipment and body extremities in the airblast. In view of these problems the use of a complete capsule presents many advantages over ejection seats. Several designs of capsules now in the experimental stage are described.

88

Frost, R. F., "Engineering Problems in Escape from High Performance Aircraft," J. Aviation Med., 28(1):74-77, February 1957.

ABSTRACT: A discussion of the elements of over-all problem of ejection: (1) Decision to abandon the aircraft; (2) operation of emergency controls; (3) removal of obstructions to egress; (4) egress from the crew station; (5) avoidance of airplane structure after egress; (6) prevention of injury caused by impact pressure, temperature, deceleration and/or tumbling; (7) prevention of injury caused by ambient pressure and/or temperature; (8) retention, and protection until use, of life-saving and survival equipment; (9) operation of live-saving equipment; (10) prevention of injury during landing, considering both vertical and horizontal velocities, and type of surface encountered; (11) counteracting effects of surface environment, including hunger and thirst; (12) facilitating search and recovery operations by friends; avoiding these operations by enemy; (13) training in operation and maintenance of the system.

89

Fryer, D. I., The Effects upon Man of Exposure to High Ram Pressure Loads, Rept. No. FPRC-1167, Institute of Aviation Medecine, Farnborough, Great Britain, ASTIA AD 267789, July 1961.

ABSTRACT: A study is reported of human tolerance to wind blast, or ram pressure, using a rotating beam channel underwater centrifuge system with specially constructed seat and pylon to simulate the high Q loads of ejection escape in the air. Descriptions are given of the design and construction of the seat, restraint, communications, breathing gear, and instrumentation used to obtain physiological and mechanical data during the tolerance testing experiments. Results are summarized with regard to tolerance, electrocardiogram, intrathoracic and abdominal pressures, trunk thickness, separation loads on arms and legs, and injuries.

90

Fryer, D. I., Operational Experience with British Ejection Seats, A Survey of Medical Aspects, Rept. No. FPRC-1166, Flying Personnel Research Committee, Great Britain, ASTIA AD 267 788, July 1961.

ABSTRACT: A survey is presented of experience in the emergency use of ejection seats of British design and manufacture. The escapes and attempted escapes included are believed to constitute a complete list of ejections from aircraft flown by the Royal Navy, the Royal Air Force, the Ministry of Aviation (formerly Ministry of Supply), and the British aircraft industry up to 1st July, 1960. It does not include test ejections carried out in the development of ejection seats, or the R.A.F. experience with American seats. Although reference to the indications for ejection and the mechanism whereby this is executed if frequently necessary, the primary aim is a medical survey of the difficulties inherent in escape by this means, and the nature, causes and contributory causes of injury during and following ejection.

91

Galiana, T. de, "New Techniques of Parachuting (Techniques Nouvelles de Parachutage)," Atomes (Paris), 7(79):333-337, 1952

ABSTRACT: This is an illustrated summary of the functioning of the ejection seat and the physiological effects of high-altitude bailout. The outlooks of recently developed techniques, such as the ejection capsule, are briefly discussed.

92

Gatling, F. P., Ejection Seat Study, Rept. No. AM 2-59, Naval Aviation Safety Center, Norfolk, Va., ASTIA AD 220 667, 1959.

ABSTRACT: The ejection rate for calendar 1958 was the highest in the history of Naval aviation, but there is an indication that the rate of increase is slowing. Lack of altitude is still the greatest factor in unsuccessful ejections. There was a large increase in on-the-deck ejections in 1958, and the mean altitude at which ejections were made in 1958 was the lowest yet recorded, 7474 feet. There was a substantial increase in fatal ejections that began above 3000 feet. The mean speed at which ejections are made continued to decrease to 217 knots. Attitude data again failed to reveal any connection between attitude and fatal injury. Among aircraft that had at least 20 ejections, the FJ series aircraft had the smallest percentage of fatal injuries.

93

Gell, C. F., "Table of Equivalents for Acceleration Terminologies," J. Aerospace Med., 32(12):1109-1111, December 1961.

94

"Getting Away with It, Martin-Baker Ejection Seat, Mks 2, 3, and 4," Flight, 748-751, 19 November 1954.

95

Glass, C. M., and W. H. Kirby, Jr., "Bone Damage Assessment Due to Impact of Ballistic Fragments," Proceedings of 1964 San Diego Conference on Biomedical Engineering, 1964.

ABSTRACT: This presentation has to do with the establishment of a mechanistic-empirical model for human bone damage due to the impact of small ballistic fragments. The determination of basic mechanical properties of human bone is central to the problem. A bone damage criterion is established that depends on the complete breaking of a given bone volume. Among the imposed conditions on the energy dissipation in the fracture process are: fragment deformation, elastic deformation of bone, creation of new surface due to bone fracture, propagation of fractures, and propagation of elastic-plastic waves in bone.

96

Goldman, D. E., "Effects of Vibration on Man," Handbook on Noise Control, 11-20, McGraw Hill Book Co., New York, N. Y., 1957.

ABSTRACT: The mechanical effect of vibration on the body is to produce motion and relative displacement. Large organs may pull on supporting ligaments and cause crushing injuries to soft tissues. Thermal effects are a direct consequence of absorption of vibrational energy. None have been observed at low frequencies but many at ultrasonic frequencies where animals may be heated to a point beyond their capacity to dissipate the heat, with consequent thermal death. Biological responses to vibration represent essentially a failure of the body to remain a passive system. Mechanical stimulation is detected by the auditory and vestibular systems, mechanical skin receptors, and internally located proprioceptors. Vibration can affect people's attitudes, feelings and work performance. Major injuries resulting from vibrations are those of hearing loss from high-level noise and hand injury from the continued use of vibrating hand tools. A survey is presented of the human body as a dynamic mechanical system and of the effects of vibration on man and his various parts. Included are tables of the physical properties of the human body, acoustical properties of soft tissues, mechanical impedance of surface of thigh, stomach, upper arm, and mastoid.

97

Goldman, D. E., "Mechanical Forces Acting on Aviation Personnel," J. Aviation Med., 17(5):426-430, October 1946.

ABSTRACT: Aviation personnel, especially those in military service, are subjected to a wide variety of mechanical forces including changes in ambient pressure, acceleration, wind blast and vibration as well as the forces associated with parachute escape, crashes, explosions and missile casualties. Little is known of the actions of these forces or of means of protection against them.

Eventually it should be possible to accumulate a background of information sufficient to permit generalizations and to allow specific predictions to be made as to tolerances and requirements for protection.

A listing of complexities must be made to enable an intelligent choice to be made of methods for handling problems which must be solved.

A first step, the performance of a structural analysis of the human body, involves a study of the geometrical and physical layout and the determination of the elastic properties of the various parts and connections.

Secondly, a vibration analysis should yield considerable information of value. Resonance measurements can be used to find natural frequencies, damping coefficients, effective masses and spring constants.

From such orderly investigations, it should be possible to learn a great deal about basic physiology and some of its practical consequences. A table of human tolerance limits of various grades and for various forces is essential for engineers concerned with the design of aircraft and of other machinery involving close human association.

98

Goldman, D. E., "The Biological Effects of Vibration," presented at US Armed Forces, National Research Council, Committee on Hearing and Bioacoustics, Washington, D. C., ASTIA AD 256 926, April 1961.

ABSTRACT: This report discusses the effects of vibration on man. It summarizes briefly:
(a) the measurement of vibration,
(b) the production of controlled vibratory stimulation for research purposes,
(c) the injurious effects of vibration,
(d) discomfort due to vibration,
(e) effects of vibration on task performance, and
(f) beneficial uses of vibration.

99

Goldman, D. E., and H. E. von Gierke, "The Effects of Shock and Vibration on Man," Lecture and Review Series, No. 60-3, Naval Medical Research Institute, Bethesda, Md., 8 January 1960.

ABSTRACT: This review deals with three problems: 1) the determination of the structure and properties of the human body considered as a mechanical as well as a biological system, 2) the effects of shock and vibration forces on this system, and 3) the protection required by the system under various exposure conditions and the means by which this protection is to be achieved. Man, as a mechanical system, is extremely complex and his mechanical properties are quite labile. He is also a human being and in this capacity refuses to permit destructive testing but will nevertheless expose himself carelessly to mechanical damage which may arise from situations of his own making and will than demand a degree of protection against this damage which shall be almost impossibly effective, unhampering, and cheap. Because of such conflicting attitudes there is very little reliable information on the magnitude of the forces required to produce mechanical damage to people. It is therefore necessary to use experimental animals for most studies on mechanical injury. However, the data so obtained must be subjected to careful scrutiny to determine the degree of their applicability to humans, who differ from animals not only in size but in anatomical and physiological structure as well. It is only occasionally possible to obtain useful information from situations involving accidental injuries to man, since while the damage can often

be assessed, the forces producing the damage cannot. It is also very difficult to obtain reliable data on the effects of mechanical forces on the performance of various tasks and on subjective responses to these forces largely because of the wide variation in the human being in both physical and behavioral respects. Measurement of some of the mechanical properties of man is, however, often practicable since only small forces are needed for such work. The difficulty here is in the variability and lability of the system and in the inaccessibility of certain structures.

100

Grandpierre, R., F. Violette, J. Fabre, and Y. Houdas, "Physiological Problems Presented by Supersonic Ejections. 1. (Problems physiologiques poses par les ejections supersoniques. 1)," Forces Aeriennes Francaises, No. 175: 667-678, November 1961.

ABSTRACT: At equivalent speeds of 1, 100 km. /hour many types of ejection seats now in use do not afford enough protection to the pilot, and the mortality of ejection at these speeds is high. The disturbances produced by the different physical parameters of high-speed ejection and the relationships between spin of the seat, the mass of the seat, altitude, and deceleration are analyzed. The rotation of the pilot after his release from the seat during the free-fall period and the control of rotation by the parachutist are discussed. A final section deals with the mechanical and physiological effects of ejection and rotation upon equipment and areas of the body.

101

Grandpierre, Violette, Fabre, Marchesseau, Ginet, and Cholin, "Study of Vertebral Fractures Observed After Forced or Faulty Landings (Etude des Fractures Vertebrales Observes lors D'Atterrissages Forces ou Defectueux)," Rev. Med. Aero., 3:525-536, November-December 1963.

ABSTRACT: An analysis is presented of 16 cases of vertebral fracture occurring during 299 forced or faulty landings in the French Air Force from January 1954 to March 1961. None of the vertebral fractures was associated with accidents occurring entirely on a landing strip. All the vertebral fractures occurred in one- or two-seat aircraft, and the proportion of fractures was greater in accidents involving American jet aircraft than other jet aircraft or helicopters. Fourteen of the 16 fractures occurred at the dorso-lumbar junction, presumably because of the position of lumbar hyperlordosis assumed by the pilots in preparation for a crash. Analysis of accidents involving French and American jet aircraft in terms of pilot weight and height, weight of the aircraft, pilot restraint, seat composition, distance of the pilot from the bottom of the fuselage, position

of the landing gear, stopping distance, speed at the time of impact, and position of the wings indicates that the higher rate of vertebral fractures in American aircraft was due to wing position. It is suggested that wings located low on the aircraft tend to protect the pilot from vertebral injury during crashes in which the landing gear is retracted.

102

Greenberg, S. H., Underwater Escape Program. Description of F86D-11 Airplane 50-Foot Drop Test. Key West, Florida. 25 March 1958, NADC-ED-5816, Interim Rept. No. 3, Naval Air Development Center, Johnsville, Pa., ASTIA AD 231 439, 25 August 1958.

ABSTRACT: Tests were performed to determine (1) the effect of high-velocity vertical entry on the sinking time of aircraft in water; (2) the structural damage sustained by the aircraft on impact; and (3) the physiological shock the pilot suffers when subjected to water collisions of this nature. Damage resulting from implosion of the canopy due to depth pressure and the accompanying physiological implications are also discussed. Shock loadings sustained by the anthropometric dummy in the F86D-11 aircraft reached a peak acceleration value of 62 g, with values well above 25 g for 30 msec. This shock loading was greater than that sustained by any other part of the airframe when the complete system was subjected to the 50-ft. fall. The acceleration has a rate of onset of approximately 6000 g/sec. which, at the g loading and duration of sustained shock, represents values well above the threshold of vertebral damage, signifying a high expectancy for extensive spinal injury. The opening in the canopy resulting from the implosion appeared to be large enough to permit egress of the pilot and his equipment from the cockpit. Only 19 sec were required from entry to submersion. The increase in the rate of submergence in the latter test must have been contributed by the higher entry velocity, accompanied by greater water penetration of aircraft, and by extensive impact damage which destroyed watertightness and buoyancy of the airframe.

103

Guill, F. C., A Study of Data Related to Vertebral Injuries Sustained During U. S. Navy Martin-Baker Mk 5 Series Ejection Seat Usage, presented at the 14th Meeting of the Emergency Egress Group, Grumman Aircraft Engineering Corporation, Bethpage, L. I., N. Y., July 1962.

ABSTRACT: Although the Martin-Baker MK 5 Series Ejection Seats provide a considerably improved escape capability over that of the Standard Navy Ejection Seat (with the NAMC Type II Catapult), considerable concern has been expressed over the vertebral injury rate resulting from its use.

Therefore, it is the purpose of this study to examine, both graphically and statistically, such data currently available, as a result of service ejections, as might be determined by physical and mathematical analysis, to be a probable causative factor of vertebral injury. Additionally, other data, which have received considerable support as causative factors, will also be examined. These data are available in the Medical Officer's Report (MOR), the Aircraft Accident Report (AAR), and in coded abstract form in the Naval Aviation Safety Center's ejection data machine runs.

A further purpose of this study is to recommend the collection of data, not currently available, which appears to have a possible effect on the sustaining of vertebral injuries.

DATA EXAMINED

In this preliminary report the following types of data from the MOR's and the NAVAVSAFECEN machine runs have been examined:

1. The Ejectee's Dressed Weight
2. The Total Seat/Man Ejected Weight
3. Time of Flight Prior to Ejection
4. Altitude of Ejection
5. Speed of Ejection
6. Ejectee's Position for Ejection
7. Harness Snugness
8. Through-the-Canopy Ejections

Some data has been compared to similar data for the Standard Navy Ejection Seat.

104

Hansen, R., and D. Y. Cornog, Annotated Bibliography of Applied Physical Anthropology in Human Engineering, WADC Technical Report No. 56-30, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, ASTIA AD 155 622, May 1958.

ABSTRACT: This volume contains condensations of 121 reports in the field of Applied Physical Anthropology. A majority of the annotations are grouped under three headings, Anthropometry, Biomechanics, and Comfort; a few are included in a General Group. Working data and important illustrations are quoted directly from the original papers in most cases. A complete index is arranged by author as well as by subject. An additional list of reports (not annotated) is included as background material. Two appendices containing relevant commentary on Seating Comfort and Anthropomorphic Dummies, also included.

105

Hass, G. M., An Analysis of Relations Between Force, Aircraft Structure and Injuries to Personnel Involved in Aircraft Accidents with Recommendations for Safer Principals in Design of Certain Types of Aircraft, School of Aviation Medicine, Randolph Field, Texas, 1 November 1943.

ABSTRACT: A study of 35 aircraft accidents was made, involving principally training types of aircraft. Where possible, the relations between forces, aircraft structure and injuries to personnel were analyzed. Correlation of the data led to formulation of recommendations for modification of aircraft structure with a view toward reducing the incidence and severity of injuries to personnel involved in aircraft accidents. The most important recommendation concerned a mechanical ejection seat with an automatically operated parachute.

106

Hecht, K. E., and E. G. Sperry, Downward Ejection Flight Tests of a Shock-Absorbing Seat Firing Control System, WADC Technical Note No. 55-239, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, ASTIA AD 118 053, February 1957.

ABSTRACT: The report covers the 28 flight test ejections of a downward ejection seat conducted from a B-47B airplane between the dates of 1 April 1954 and 3 August 1954. Eighteen of these tests were accomplished at Wright-Patterson Air Force Base, Ohio utilizing dummy subjects; the remaining ten tests were performed with human subjects at Eglin Air Force Base, Florida. Measurements of the forces encountered in the wrists when utilizing a D-ring type of firing control during downward ejection are presented. Other test results, including those from two high altitude human subject ejections, obtained from motion picture records and subjective reactions of the human subjects, are reported. It is concluded that the downward ejection seat as modified for the human subject phase is a satisfactory escape device throughout the speed and altitude range tested.

107

Hegenwald, J. F., and W. V. Blockley, "Survivable Supersonic Ejection, A Case Study to Correlate Analytical, Experimental, and Medical Data by Reconstruction of an Incident," presented at the 27th Annual Meeting of the Aero Medical Association, Chicago, Illinois, Rept. NA 56-452, North American Aviation, Inc., Los Angeles, California, ASTIA AD 138762, April 1956.

ABSTRACT: An anthropomorphic dummy was ejected 4 times from a simulated F-100 airplane cockpit at 533 to 677 kn. The objective was to obtain information which could be used to prevent the recurrence of injuries which were sustained by a pilot who was ejected from an F-100A airplane over the Pacific Ocean. The M-5 catapult with an ejected weight of about 350 lb. was used. The standard F-100 ejection seat configuration was employed, except for the incorporation of the drag parachute in later runs. In addition to the photographic coverage, continuous acceleration data were provided by means of a telemetering transmitter mounted within the dummy's torso. The pilot was believed to experience, at the head (1) a maximal period of 290 msec with an acceleration greater than 20 g, (2) a period of 120 msec at an acceleration above 35 g, (3) a peak acceleration of 64 g, and (4) a rate of onset of the peak of 700 g/sec.; the direction of application was predominantly negative. At the lower torso, the pilot was believed to experience (1) a maximal period of 140 msec with the acceleration greater than 20 g, (2) a period of 45 msec at an acceleration above 35 g, (3) a peak acceleration of 50 g, (4) and a rate of onset of 1300 g/sec.; the direction of application was chest to back. The imposition of a single properly directed force vector upon the seat-man unit would benefit ejection seat escape in 3 main aspects: (1) orientation of the seat attitude to produce accelerative forces in physiologically favorable directions; (2) attentuation of acceleration magnitude at the seat occupant's extremities and (3) improvement of aerodynamic lift characteristics.

108

Hendler, E., "Compendium of Abstracts of Papers Presented at the Symposium on Biomechanics of Body Restraint and Head Protection," Office of Naval Research, Bureau of Naval Weapons, Naval Air Material Center, Philadelphia, Pa., 14-15 June 1961.

ABSTRACT: The objectives of the Symposium were to (1) review and bring up-to-date the theoretical biological knowledge on acceleration injuries, (2) review and bring up-to-date engineering progress in the design of protective devices, and (3) foster the interchange of ideas between the two disciplines with the hope of eventually developing better protection against linear acceleration.

This Compendium contains a copy of the program, those abstracts of papers which were submitted for inclusion herein, and a complete list of attendees.

109

Hess, J. L., <u>The Approximation of the Response of the Human Torso to Large Rapidly Applied Upward Accelerations by That of an Elastic Rod and Comparison with Ejection Seat Data</u>, Rept. No. ES 26472, Douglas Aircraft Co., Inc., ASTIA AD 125 558, 26 November 1956.

ABSTRACT: It has been noticed that when the human body is subjected to very rapidly applied accelerations, the accelerations at points of the body can be considerable larger than the maximum value of the applied acceleration. This paper considers the case when the acceleration is applied along the line of the spine from seat to head as in ejection from aircraft and attempts to approximate the motion of the human torso under these conditions by that of an idealized, one-dimensional, visco-elastic structure.

The simple case of a homogeneous elastic rod is discussed in detail and its predictions compared with ejection seat data. The extensions to more complicated visco-elastic structures are discussed. It is concluded that the elastic rod is a fairly good first approximation, but that it is not sufficiently exact to be used in making quantitative predictions. It is also concluded that more complicated structures will require more and better data for their evaluation.

110

Hess, J. L., and C. F. Lombard, "Theoretical Investigations of Dynamic Response of Man to High Vertical Accelerations," J. Aviation Med., 29:66-75, January 1958

This paper attempts to investigate the dynamic response exhibited by the human torso when subjected to large, upward, short duration accelerations of the sort encountered in ejection from aircraft, by considering a simpler mechanical system. This, if successful, would permit the determination of spinal stresses. The simplest model, the elastic rod, is chosen as a first approximation. Its predictions agree fairly well with experiments on human subjects. Among these are the lack of physical significance of rate of rise of acceleration and the dependence of dynamic stress magnification on time of rise of acceleration. It is concluded that fixed stroke ejection systems can maximize safe ejection velocity by raising the acceleration slowly to a relatively nigh maximum, while other systems can employ arbitrarily short times of rise if the acceleration does not exceed a value approximately half that which is safe in the case of slow rise.

111

Hirsch, C., "Studies on the Mechanism of Low Back Pain," Acta Orthop. Scand., 20:261-274, 1951.

ABSTRACT: The author gives an account of new technical devices which have enabled him to study the function of the lumbar intervertebral discs. His investigations support the opinion that disturbances in the variations of pressure that arise in lumbar discs are frequent in ruptures of the annulus. As a result disturbances are caused both in regard to the relative postion of the surrounding vertebrae and in regard to the deformation by which any particular intervertebral disc responds to a given mechanical strain. The variability thus occasioned even by a physiological use of the back may cause such irritation of the sensitive end organs of the long ligaments as to produce lumbar pain.

112

Hirsch, C., "The Reaction of Intervertebral Discs to Compression Forces," J. Bone Joint Surg., 37A(6):1188-1196, December 1955.

ABSTRACT: 1. Assuming intervertebral disc lesions to be the causative factor of low-back pain, our present knowledge does not allow us to explain the pathological mechanism involved.

2. Since at least 40 per cent of all patients with backache claim that the pain started because the back was subjected to extra strain, it is suggested that biomechanical studies may give a new approach for pathological and mechanical discussions.

3. An experimental approach has been adopted by which the mechanical responses of intervertebral discs can be recorded with a high degree of accuracy.

4. Two quantitatively different responses of the disc have been described. The reaction to a statically applied load takes place in the course of minutes, while the response to the dynamic load occurs within fractions of a second. The latter is characterized by vibrations in the disc.

5. Vibrations were registered with a disc under steady load. Even if a disc has reached a static equilibrium, additional rapid forces can increase the deformations to a great extent, even if these forces are relatively small.

6. Apparently insignificant traumata are not recognized by the insurance companies in many countries as cases for compensation. On the basis of the observations recorded in the experiments, it is not the violence itself that decides the extent of the damage but the trauma combined with the condition of the disc at the time of injury. The more the disc is compressed, the less additional trauma may be required to cause lesions. Degenerated discs may, under certain circumstances, show a decreased tolerance to stress.

113

Hirsch, C., and A. Nachemson, "Back Injuries After Catapult Ejection (Ryggundersokning av Katapultutskjutna)," Meddelanden fran Flyg-och Navalmedicinska Namnden (Sweden), 12:1-4, 1963.

ABSTRACT: Back injuries were investigated in 55 pilots who had ejected from their aircraft during the period of 1957-60. Incidence, distribution,

and level of the vertebral fractures are reported. X-ray findings also disclosed spondylolisthesis, vertebral osteochondritis, Schmorl's nodules, old vertebral fractures, disc degeneration, and hemangioma. Other injuries sustained were distorsio pedis, luxatio humeroscapularis, fractura femoris, fractura sacri, and fractura sterni.

114

Hirsch C., and A. Nachemson, "Clinical Observations on the Spine in Ejected Pilots," Acta Orthopaedica Scandinavica (Sweden), 31 (2), 1961.

ABSTRACT: During the period from 1957 through 1960, 55 pilots of the Swedish Royal Air Force have rescued themselves by catapult ejection.

The entire group has formed the subject of an orthopaedic evaluation, which included roentgenologic and tomographic examination.

Thirteen of the subjects, or 27 per cent, were found to have incurred vertebral fractures. The injuries invariably consisted of compression fractures of the vertebral bodies. In 5 cases the damage involved only one vertebra, whereas 8 cases showed multiple injuries.

Both with regard to the frequency of the injuries and in the distribution of the levels involved, the middle part of the thoracic spine dominates. The injuries have in no case caused neurologic disorders. All injured jet pilots were able to return to active service after a convalescence of 2 months on an average.

Secondary findings disclosed by the roentgenologic examination were spondylolistheses, defects indicative of Scheuermann's disease, Schmorl's nodules, one case of haemangioma, degeneration of a single disk, and an old vertebral fracture which had healed. In none of these cases does the ejection appear to have resulted in symptoms of injuries which might be connected with the above defects.

Five pilots had occasionally experienced low back pain prior to the catapult ejection. In none of these cases were the symptoms aggravated after the ejection.

The injuries incurred as a result of the catapult ejection have been of a mild character. It would seem, therefore, that the technical solution of the ejection escape must be regarded as acceptable, considering the seriousness of the situation in which the pilot finds himself on being forced to abandon his aircraft.

115

Hirsch C., and A. Nachemson, "New Observations on the Mechanical Behavior of Lumbar Discs," Acta Orthopaedica Scandinavica (Sweden), 23:254-283, 1954.

ABSTRACT: 1. The aim has been to study the mechanical behaviour of lumbar intervertebral discs when subjected to stresses.

2. Experimental devices have been constructed. This has made it possible to follow movements and changes in shape in discs within very short periods of time.

3. The mechanical behaviour of the disc differs according to how fast the stresses set in. If a disc is kept loaded a certain amount of compression occurs until an equilibrium is reached. If a disc is subjected to a short momentary load it starts to oscillate.

4. Diagrams are presented showing the amount of compression as well as the lateral expansion that occur after increasing loads up to 100 kg in both normal and degenerated lumbar discs. It is striking to see how little the discs are deformed. 100 kg gives a compression in a normal disc of about 1.4 mm and an expansion of 0.75 mm. In a degenerated disc, i.e. when the annulus fibres are ruptured, a compression of 2 mm was the effect of a 100 kg load.

5. There was no difference in the bearing capacity, whether the arches were intact, or a hemilaminectomy or a total laminectomy was performed. This supports the idea that the discs themselves play by far the most important role in carrying loads.

6. Loads lasting seconds give perfect elasticity curves of the same shape as in the hyaline articular cartilage. Compression of this nature can be repeated any number of times without disturbances in the mechanical response of the disc.

7. If the disc is under load and has assumed an equilibrium and is then subjected to an increasing strain for a short period of time, it resumes the form it had before the additional load was brought on. The disc has the power of adaptation to mechanical stresses. However, the greater the load applied the less will be the capacity for shock absorbing.

8. When an intervertebral disc is subjected to rapidly acting forces it starts to oscillate.

9. Oscillations have been registered while the disc has been under a static load from 10 to 130 kg. This means that, even if a disc has reached a static equilibrium, additional rapid forces can increase deformations to a very great extent, even if these forces are relatively small. Because the deformations occur frequently during a short period of time (tenths of seconds), this means a hitherto unknown stress of considerable magnitude.

10. The smallest trauma can produce great stress in a low back if the force acts rapidly. The changes in shape in a disc are of such intensity and frequency that it is hardly believable that muscular reaction can stabilize and protect a back from these variations in form. They are entirely due to the biophysical construction of the disc material itself.

116

Hodgson, V. R., L. M. Patrick, and H. R. Lissner, Experimental Response of the Seated Human Cadaver to Acceleration and Jerk with and without Seat Cushions, Biomechanics Research Center, Wayne State University, Detroit, Mich., June 1963.

ABSTRACT: This paper describes tests conducted on three cadavers in the seated position and accelerated in the caudocephalid direction, with 18 G jerk acceleration and jerk amplitudes to 2600 G's per second. Spring seats were used to observe effect of cushions. Experiments were conducted on 120' vertical accelerator mounted in an elevator shaft. Strain gages were mounted on various vertebrae and accelerometers attached to the seat, and on crest of ilium, sternum and head. Each cadaver was restrained with head, arm, leg, shoulder and seat belts. The objective was to determine the effect of a jerk and cushion noticed on the response of a cadaver at various levels of acceleration, on the response of the human cadaver as a spring mass system, and on strain in the vertebral column. A number of conclusions were made; among these that no cushion is better than any cushion; jerk causes overshoot of strain or acceleration of increase almost linearly up to a maximum value dependent upon the mean acceleration, the degree of overshoot of acceleration on the body increases in severity with distance from the seat, and this overshoot is most severe and critical in some locations in the posterior parts of the vertebrae due to process interference during caudocephalid loading of the vertebral column.

117

Hetzar, W., "The Traumatic Injuries of the Invertebral Discs of the Vertebra Body Section," Deutsche Zeitschrift fur Chirurgie (Berlin), 396-439, 1939.

118

Holcomb, G. A., Human Experiments to Determine Human Tolerance to Landing Impact in Capsule Systems, Stanley Aviation Corp., Denver, Colo.

119

Holcomb, G. A., "Impact Studies of the United States Aerospace Industry," presented at Impact Acceleration Symposium, Proceedings: Publ. 977, NAS-NRC, pp. 83-119, Brooks Air Force Base, San Antonio, Tex., 27-29 November 1961

ABSTRACT: Aerospace Industry has engaged extensively in analytical studies of impact acceleration stress and sparingly in experimental studies. In most cases studies were the result of the need to evaluate a definite system rather than a desire to engage in basic research since the present published tolerance to impact acceleration allowables are limited in their use to the designer.

The most significant contributions have been the development of mathematical models and human tolerance to acceleration computers by dynamicists, and experimental data using biological specimens derived from capsule ground landing system tests. These developments are discussed in detail in this paper.

As a result of analytical and experimental studies accomplished by Aerospace Industry and industry's chronic problems in designing to present published human tolerance to acceleration allowables, the following recommendations are made:

(1) new methods of determining body response be evolved based on mathematical techniques,

(2) experimentations of the future be correlated to the mathematical approaches provided by dynamic studies, and

(3) new experiments be accomplished to provide extremely abrupt impact acceleration data dealing with both single pulses and pulses superimposed on sustained accelerations.

120

Holcomb, G. A., and M. Huheey, "A Minimal Compression Fracture of T-3 As a Result of Impact," presented at Impact Acceleration Symposium, Proceedings: Publ. 977, NAS-NRC, pp. 191-194, Brooks Air Force Base, San Antonio, Tex., 27-29 November 1961.

ABSTRACT: A 22 year old, 5'11", 175 pound male was chosen as one of the test subjects in the B-58 escape capsule ground landing tests, having passed a thorough medical examination. No ill effects were experienced on any of his first three drops as supported by close medical surveillance.

However, after the fourth drop, the subject experienced a mild compression fracture of T-3.

Some of the possible events which could have contributed to this injury are discussed.

121

Hooton, E. A., A Survey in Seating, Heywood-Wakefield Co., Harvard University, Boston, Mass., 1945

ABSTRACT: Includes three sections: Survey of body measurements relative to dimensions of seats; notes on variations of the curves of the spine in standing and sitting; and a survey on the curves of the spine in the sitting position. Eight measurements were taken on each of 3,867 (1908 females, 1959 males) between ages 17 and 89, stated to be representative of the U.S. population. A description of the measuring chair, the contour sand mold chair, and recommended seating dimensions are given.

122

Hoover, G. W., "Predictions for the Future". --In: Problems of Escape from High Performance Aircraft, J. Aviation Med., 28(1): 95-100, February 1957.

ABSTRACT: Man's psychophysiologic limitations are the constants around which any man-machine system must be designed. Contemporary and future vehicles must meet requirements of efficiency, versatility, safety, reliability, and economy. With these ideas in mind predictions on future aerospace vehicles may be made. A feasible future development in line with current trends is the "standard cockpit" system, a cockpit which would be interchangeable between trainer, fighter, bomber, and reconnaissance aircraft. In addition, it might function as an emergency escape capsule providing for pilot safety and the recovery of expensive equipment.

123

"Impact Acceleration Stress with a Comprehensive Chronological Bibliography," A Symposium, Publ. 977, NAS-NRC, Brooks Air Force Base, San Antonio, Tex., 27-29 November 1961.

124

Internal Vibrations Excited in the Operation of Personnel Emergency Escape Catapults, Memo Rept. MR-340, Frankfort Arsenal, Philadelphia, Pa., ASTIA AD-51 792, 26 November 1946.

ABSTRACT: Studies of the catapults, T2 and T4, emergency escape personnel, show that the accelerations transmitted throughout the body by the catapult differ in magnitude and phase from the acceleration applied to the center of gravity of the system. Typical acceleration measurements on dummy and human subjects are shown. Comparisons of these records with independent measurements of pressure-time in the catapult and with travel-time data show that strong internal vibrations of the several massive components of the ejected system are superimposed upon the motion of its center of gravity. As a consequence of these vibratory components, the internal elastic stresses in the body, depending on the phase of the vibration, at their peaks will exceed the values which would be required for the acceleration of an equivalent rigid body to the required terminal velocity under action of the same applied forces. Since the estimated safe limit for these elastic stresses is not very high compared to the stress level to obtain the required center of gravity acceleration, the excitation of such internal vibratory motion imposes a distinct limitation in the application of the catapult to personnel escape.

125

Interim Ejection Seat Study, Interim Rept. for 1 January to 30 June 1958, U.S. Naval Aviation Safety Center, Norfolk, Va., ASTIA AD-211169, 1959.

ABSTRACT: This is a report on ejections from U.S. Navy aircraft for the period January 1 to June 30, 1958. It is the policy of the Naval Aviation Safety Center to publish a yearly summary of ejections. In order to furnish more current data to interested bureaus, agencies, manufacturers, etc., about emergency escapes by ejections, the Naval Aviation Safety Center is publishing an interim report for the six month period. The general format followed in this interim report is a factual presentation with little or no interpretation. The complete analysis of the emergency use of the ejection seat will be published in the yearly summary.

Sixty-five ejections occurred during the period January 1, 1958 to June 30, 1958. Forty-six ejections were recorded for this same period in 1957. The rate per 10,000 flying hours is 1.27 for the six-month period. This is in contrast to a rate of .98 for the first half of 1957. The fatality rate for the period covered by this report is .21. The fatality rate for the corresponding period of 1957 was also .21.

126

Interim Ejection Seat Study, Interim Rept. for 1 January to 30 June 1959, U.S. Naval Aviation Safety Center, Norfolk, Va., ASTIA AD-232431, 1959.

ABSTRACT: This is a report on ejections from U.S. Navy aircraft for the period 1 January to 30 June 1959.

It is the policy of the Naval Aviation Safety Center to publish a yearly summary of ejections. In order to furnish more current data to interested bureau, agencies, manufacturers, etc., about emergency escapes by ejections, the Naval Aviation Safety Center is publishing an interim report for the six month period. The general format followed in this interim report is a tabular presentation with no interpretation. The complete analysis of the emergency use of the ejection seat will be published in the yearly summary.

127

Jager, M., "At 2400 KM/HR.: Exit...? (Bei 2400 km/st: Aussteigen...?)," Flug-Revue (Stuttgart), (12):18-20, 22 December 1956.

ABSTRACT: American research and experiences with ejection at high altitudes and supersonic speeds are briefly described. It is recognized that the progressively increasing speeds and higher altitudes exceed the protection offered by further development of the ejection seat. Instead, the new safety design concept consists of a completely enclosed ejection capsule encompassing the pilot and the cockpit.

128

Jones, W. L., "A Study of Bailouts for a Five-Year Period in the U.S. Navy," J. Aviation Med., 22:123-131, 155, April 1951.

ABSTRACT: Factors involved in 850 emergency bailouts in the U.S. Navy have been presented. Most of these bailouts were made from fighter and attack type aircraft. Roughly, 85 per cent of the bailouts were successful—lives were saved; and almost 50 per cent were not injured at all. It is noteworthy that most of this population had little choice but to abandon their aircraft. The difficulties encountered have been enumerated. The attitude, speed, and altitude of the plane at time of exit, reasons for bailout, and the extent and cause of injuries have been discussed. The need for bailout training is emphasized.

129

Jones, W. L., and W. F. Madden, "Ejection Seat Accelerations and Injuries," presented at 34th Annual Meeting of the Aerospace Medical Association, Los Angeles, Calif., 28 April-2 May 1963.

ABSTRACT: A review of accelerations measured on ejection seat catapult tests, over the past four years, indicates a much wider range of values than was originally believed. This explains, in part, the occasional injury where no injury occurred in an almost similar set of circumstances. To reduce these values and obtain more performance capability a Rocket Assisted Propulsion Ejection Catapult (RAPEC) was developed by the Naval Ordnance Test Station, China Lake. This system is completely interchangeable size-wise with the present catapults resulting in much lower accelerations with increased trajectory. A review of the back injuries is given along with clinical management and results.

130

Jones et al., "Ejection Seat Accelerations and Injuries," Aerospace Med., 35(6): 559-562, June 1964.

ABSTRACT: The U.S. Navy aircraft emergency escape systems have saved many lives, but have caused a 21 per cent incidence of fractured vertebrae. A program is underway to reduce the g loading and obtain at the same time better performance by means of a rocket propelled ejection system which combines a lower boost phase followed by an even lower sustained rocket thrust phase. The aviators with vertebral fractures have, in general, fared well. Most have returned to full flight status. Early ambulation seemed to assist in the healing process as well as the maintenance of aeronautical adaptability and high morale. Canopy ejections continue to present special problems which are being met in part by training the aviator to keep his seat low for ejection.

131

Jones, W. L., and E. C. Gifford, U.S. Navy Aircraft Weapon Systems Anthropometry, Bureau of Medicine and Surgery, U.S. Navy Department, Washington, D. C.

ABSTRACT: The flight surgeon is called upon to assess clinically the capabilities of potential aviators in performing as combat military aviators. Disproportion of the aviator and his cockpit will degrade this performance as much, or more than, many other physiological or pathological conditions. In addition, new aviator equipment now requires measurements not heretofore taken and modern aircraft weapon systems require very precise operator anthropometry.

After an exhaustive study of cockpit dimensions of the naval aircraft inventory validated by actual measurements using a newly-developed plastic anthropometric manikin, it was concluded candidates could be matched best with cockpit sizes through the use of aircraft and aviator categorization based on sitting height and stature, with appropriate minimums and maximums. Anthropometric measuring devices have been designed and are being field tested for use in this program. Candidates may be assigned a size category which would become part of their official designation number. Then, by knowing cockpit sizes, the Bureau of Naval Personnel could assign the individual aviators to squadrons utilizing aircraft with commensurate cockpits. This anthropometric field test is supplying data to add to the "measured naval aviator population" and new modified tables will be appended. Supplementing this field test, a Navy anthropometric team with special devices, technicians and equipment is measuring 2,000 of the naval aviator population covering 65 dimensions including center of gravity determinations.

Now the aviation clinician, the flight surgeon, must carefully screen the aviator applicants by a host of measurements in addition to the traditional height, weight and girth.

132

Juin, G., "Vertebral Pains, Occupational Diseases of the Flier? (Les douleurs vertebrales, maladies professionnelles du navigant?)," Pilote de ligne (Paris), (33):54-59, 1963.

ABSTRACT: A considerable increase in the incidence of painful vertebral disorders, originating from the aircraft seat, has been found in flying personnel. Many spinal disorders arise from the actual work conditions. The perpetual lateral torsion and flexion of the trunk of mechanics working on aircraft, and the various gestures of hostesses and stewardesses during flight under unbalanced conditions also contribute to cases of spinal pathology. The physician faced with patients with spinal problems must diagnose the disorder, analyze the exact causes, and prescribe curative and preventive treatment. Since spinal disorders appear to arise from human and material factors, it is suggested that the physician and engineer cooperate to protect the health and safety of aircraft personnel by modifying seat design, lessen vibrations (especially in helicopters), etc.

133

Kalogeris, J. G., Pilot Emergency Escape Upper Torso Harness Support Development Test Model F 106A, Convair Rept. No. 9999, General Dynamics Division, Convair Aircraft Corp., ASTIA AD-144 950, August 1956.

ABSTRACT: An upper torso harness was developed to relieve a share of the forces

resulting from accelerations above 20 g. The harness was fabricated from standard CVAC FAB 375 (nylon cloth), CVAC WEB 217 (1 3/4- x 1/8- in. nylon webbing) and standard parachute hardware. Initial seat drop tests were conducted with a fully anthropomorphic test dummy without the upper torso harness to determine the various loads the torso is subjected to under varying g forces. The harness was then secured to the body in a manner which simulated the instant prior to actual ejection. Drop tests were then conducted with the torso harness from 5 to 28 g's. About 10 human drops at accelerations up to 11 g's were conducted with and without the harness. Satisfactory seat and spinal load relief (about 50% of the loads were relieved) was realized with the harness. About 70% of the spinal and pelvic loads were relieved with the harness and proportional load system combination. The harness maintained its effectiveness when worn over several combinations of flight clothing. No physical discomforts were reported during the drop tests.

134

Keegan, J. J., "Alterations of the Lumbar Curve Related to Posture and Seating," J. Bone Joint Surg., 35-A(3):589-603, July 1953.

ABSTRACT: The most common cause of low-back pain related to seating is posterior protrusion or extrusion of lower lumbar intervertebral discs. The normal curve of the lumbar spine in adult man is determined by maintenance of the trunk-thigh and the knee angles at approximately 135 degrees. Alteration of this normal lumbar curve, either an increase in standing erect or a decrease in sitting or stooping, is caused largely by the limited length and consequent pull of the trunk-thigh muscles of the opposite side. The most important postural factor in the causation of low-back pain in sitting is decrease of the trunk-thigh angle and consequent flattening of the lumbar curve. The next most important cause of low-back pain in sitting is lack of primary back support over the vulnerable lower lumbar intervertebral discs. Added factors of comfort in seating are the shortness of the seat, a rounded narrow front border, an open space beneath for better positioning of the legs, and permissive change of position in the seat. The design of all seats, regardless of model or size, should be based on this knowledge.

135

Koochembere, C. T., "Human Factors Relative to the Problem of Escape-Ejection Accelerations," presented at Conference on Problems of Emergency Escape in High Speed Flight, Wright-Patterson Air Force Base, Ohio, ASTIA AD-14 347, 29-30 September 1952.

ABSTRACT: This paper concerns itself with research work associated with ejection accelerations and how this data has been utilized in the development of equipment that will safely eject pilots from high performance aircraft. German and

British experiments on human tolerance to acceleration are reviewed. On the basis of the data obtained in these experiments, the Martin Baker Aircraft Company developed a high-performance catapult, on which test subjects were exposed to 17-21 g over period from 0.15 - 0.25 seconds. No injuries or undesirable side reactions were sustained. The firm developed a face curtain "for effectively maintaining the proper body and head position and relieving some of the loading on the vertebrae during ejection strokes without injury or notable discomfort.

136

Latham, F., "A Study in Body Ballistics: Seat Ejection," Proceedings of the Royal Society, B, 147:121-139, 1957.

ABSTRACT: Escape from high-speed aircraft has necessitated the development of ejection seats. This introduced the physiological problem of the maximum acceleration and rate of change of acceleration which can be sustained by the seated human body along the vertical axis of the spine. The ballistic behavior of the human body has been studied by various experimental techniques.

Natural frequencies and damping characteristics of the ejected system (man and seat) have been determined by subjecting the instrumented body to continuous vibrations over the frequency range from 1 to 20 c/s, and also by investigation of its response to spike- and step-force functions in sledge-hammer and seat-drop experiments. Results with different cushion and spring systems interposed between man and seat were compared and related to accelerometer records obtained from live subjects on ejection test rigs. The data derived from these experiments has been studied on an electronic servo simulator and the general physiological requirements for ejection-seat guns have been defined.

Under these conditions a rate of change of acceleration of 300 g/s with a maximum peak acceleration of 25 g should be considered as limiting factors for accelerations tolerable by the body. This implies that the characteristics of the acceleration applied to the seat should be less than these figures by an amount depending on the elasticity of the cushion employed. It is suggested that the optimum duration of the thrust is approximately 0.23 sec. and a maximum overshoot in peak acceleration in the body would result with a rate of change of acceleration of 400 g/s applied to the seat.

137

Laurell, L., and A. Nachemson, "Some Factors Influencing Spinal Injuries in Seat Ejected Pilots," Aerospace Med., 34(8):726-729, August 1963.

ABSTRACT: During the years from 1957 through 1960, 55 successful catapult seat ejections were made by Royal Swedish Air Force personnel. They have formed the subject of an analysis to determine the incidence of vertebral fractures. The age of the pilots ranged from 20 to 42 years. The entire group was subjected to roentgenographic and tomographic examination, and questioned about clinical symptoms before, during and after the ejection.

In addition to the clinical examination, the following factors have been subject to analysis: a) type of aircraft, b) altitude and speed of aircraft, c) controlled or uncontrolled attitude of aircraft at time of ejection, d) ejection during positive or negative acceleration, e) acceleration peak and duration, f) body position in seat, g) type of ejection-handle used, h) crewmember's height in seat, i) helmet worn or not, j) seat belts strapped or not.

The incidence of vertebral fractures was in this series influenced by the following factors:

a) acceleration peak and duration. In 23 ejections made from aircraft type 29 at maximum acceleration of 15-20 g, no fractures occurred. In 29 ejections from aircraft type 32, at maximum acceleration of 20-25 g, 12 fractures occurred. However, the performance of the latter type of aircraft has necessitated higher accelerations. Since the fractures without exception were of a relatively mild type and in no case have resulted in disability or permanent symptoms, their incidence has not warranted a lowering of the acceleration requirements, which would considerably increase the risk of collision with the aircraft structure.

b) Ejection in cases during uncontrolled attitude, which in most cases meant that the crew was not allowed time to properly prepare for the ejection, has caused isolated or multiple fractures in 8 out of 13 flyers involved. In five of these cases, moreover, the ejection was effected during negative acceleration, resulting in five spinal fractures.

For ejections during controlled aircraft attitude the rate was 4 out of 39 (Aircraft type 32: 4 out of 20).

138

Lawton, A. H., "Human Factors in the Operations and Design of Aircraft," J. Aviation Med., 23:254-258, 306, 1952.

ABSTRACT: Human factors in aviation embrace three broad divisions: (1) aviation medicine, which familiarizes pilots with their equipment, safety measures, and preventive medical aspects; (2) human engineering, which analyses limitations of human response to the aircraft and its equipment; and (3) human resources which relate to selection, classification, aptitude measurement, training, and human relations, taking into the account the diversified nature of human beings. Psycho-physiological aspects of noise, vibration, use of pressurized cabins, use of ejection

seats and all kinds of protective equipment, and the impact of speed are discussed. Animal experiments have a great value in furthering research but ultimately each device, method, and principle has to be tested by "human guinea pigs."

139

Lehmkohl, J. C., Spinal Acceleration Measurements on a Pilot-Dummy Ejected from a P-61 Airplane in Flight, Serial No. TSEAC12A-45341-2-5, Army Air Forces, Materiel Command, Engr. Division, ASTIA ATI-10 794, 1 July 1947.

ABSTRACT: It is concluded that the existence of a vibrating system; consisting of the ejection seat, the cushioning media, and the dummy; which induces the high peak accelerations is further substantiated by the results of these tests. The peak values of spinal acceleration, as recorded, exceed the present known physiological tolerances of a human subject. The weight of the ejection charge has a very small effect on the peak value of spinal acceleration. The primary factor effecting the magnitude of the spinal acceleration peak is the angle of ejection. Within 0.15 seconds after the catapult separation the spinal acceleration of the dummy stabilizes at approximately -2 g for the duration of the record. It is recommended that ground tests be conducted to obtain additional data concerning the effect of ejection angle, and that corrective action be taken towards the modification of the means of cushioning in order to eliminate or reduce the excessive peak accelerations.

140

Lenz, R. C., Kinetic Measurements on a Pilot-Dummy Ejected from a P-61 Airplane in Flight, Air Materiel Command, Wright-Patterson Air Force Base, Ohio, ASTIA ATI 42654, July 1946.

ABSTRACT: Data are presented relative to the forces which act on a pilot-dummy when subjected to ejection by a catapult mechanism from an F-61 fighter airplane in flight. It was ascertained that the average velocity of ejection obtained in these tests closely approximates the velocity for which the catapult was designed. The vertical acceleration, as recorded for the peak values, exceeds the present known physiological tolerance of a human being.

141

Levy, P. M., "Ejection Seat Design and Vertebral Fractures," Aerospace Med., 35(6):545-549, June 1964

ABSTRACT: Ejection seat design contributes to the incidence of vertebral fractures sustained by aviators on ejecting from present day jet aircraft. Seat design as related to poor body positioning and excessive ejection forces is discussed. Recommendations are made for improving certain features of present day ejection seats.

A complete analysis of the causes of vertebral fractures during ejections would necessarily include parachute injuries, mechanical failures and human error factors, all of which are not within the scope of this paper. Likewise, the relative safety of the different type ejection mechanisms, i. e., rocket or catapult, is not discussed. This paper is concerned with areas in which there is evidence poor seat design features are violating biomechanical principles. The solutions to these design problems may vary but should follow these precepts:

The seat contour should maintain normal vertebral alignment without inducing flexion or extension of the spine.

The face curtain should not induce head flexion or produce additional loading of the spinal column.

The trunk-thigh angle should be maintained as close to 135° as possible.

Contact between the seat and the buttock-thigh area should be maintained during the ejection sequence.

The entire length of the thigh should be supported by the seat.

There should be an adequate seat pad to cockpit floor distance.

Harness restraint systems should not induce flexion tendencies and should be designed to adequately prevent flexion of the spine during the ejection sequence.

Shoulder harness restraint configurations should not induce loading of the spine.

The restraint systems should remain tight and comfortable.

The included angle should be engineered out of ejection seats.

The seat should be of sufficient depth.

The seat pan and pad should be securely locked in place at all times.

A seat firing mechanism initiated by any movement inducing flexion of the spine should be avoided.

An energy absorbing seat pad should be utilized.

Adequate clearance between the aviator's helmet and the canopy should be maintained throughout the entire ejection sequence.

Seats should be engineered to allow a safe ejection for all aviators regardless of size and weight or else only aviators falling within accepted anthropometric allowances should pilot aircraft with ejection seats.

Seat design and performance analysis must allow for body responses which cannot be predicted from seat measurements alone.

The maintenance of optimum vertebral positioning must be accomplished if successful ejections without vertebral fractures are to be made at all altitudes and speeds.

142

Levy, P.M., D.J. Sekinger and R.S. Stone, "A Discussion of the Nature and Source of Injury Experienced by Aviators Ejecting from F9F-8T Cougar Utilizing MK-45 Seat," presented at Symposium on Biomechanics of Body Restraint and Head Protection, Naval Air Material Center, Philadelphia, Pa., 14-15 June 1961.

ABSTRACT: An analysis of nine aviators ejecting in the MK-45 seat revealed that the more serious injuries were related to the ejection per se and were back injuries. Analysis of the MK-45 seat revealed inadequancies relating to improper positioning of the aviators and application of increased ejection forces to the ejecting aviator.

143

Lew, J., Review of Problems of Emergency Escape by Parachute Jump and Ejection Seat, Report No. BC-531-5-12, Cornell Aeronautical Laboratory, Inc., Buffalo, N.Y., ASTIA ATI-125 336, December 1949.

ABSTRACT: To obtain an understanding of the status of the problems of escape from an airplane at high speeds and altitudes, a search was made of pertinent literature. The existing literature covered only the normal parachute jump and the catapult seat ejection, methods of egress which are satisfactory at maximum speeds of 350 and 550 mph, respectively, and at a maximum altitude of 50,000 feet. Information is presented on: the conditions imposed upon the human by the two methods during egress and the descent to earth, and the reactions of the human body to these conditions.

144

Lindbom, A., "The Roentgenographic Appearance of Injuries to the Intervertebral Discs," Acta Radiol. (Stockholm), 45:129-132, 1956.

ABSTRACT: Traumatic lesions of intervertebral discs without concomitant vertebral fracture are probably rare. In such cases roentgenologic changes may be absent at the examination directly after the trauma. The height of the disc is subsequently reduced and calcifications appear around the disc mainly along its lateral margins.

145

Lippisch, A. M., and R. Noble, Trajectories of Upward Seat Ejection, TED NAM 256005, Report No. 6, Naval Air Material Center, Aeronautical Medical Equipment Lab., Philadelphia, Pa., ASTIA ATI-57 511, November 1948.

ABSTRACT: A method for determining the trajectory of a man and seat ejected upward from a moving aircraft when the initial conditions of flight and ejection are known has been derived. The mathematical derivation is highly complex, but the solution of the differential equations of motion yields a set of equations from which the position of the ejected body with respect to ground or to a point in space can be easily determined when the seven parameters used to define the boundary conditions are given. These seven parameters which comprise the initial conditions necessary for accurate calculation are airplane speed, direction and angle of inclination of flight, flight altitude, ejection velocity, angle of the seat guide rails with respect to the vertical, weight of the ejected mass, and air resistance of the mass. A particular form of the method presented can be used to determine the initial conditions of flight and ejection which are necessary for specified clearance of aircraft for particular dimensions. A preliminary investigation of the effect of the variation of four of the seven parameters is presented. The method for calculating the space and time trajectories of the ejected mass is given, and a comparison of available flight test trajectory data with theoretical calculations is shown. This analysis of trajectories and of the effects of the variable on the path of the ejected body is able to serve as a check and assurance of the validity and completeness of the aero-medical and engineering studies.

146

Lissner, H. R., "An Outline of Current Research and Objectives of Future Contributions to Investigations of Impact Injuries by U.S. Universities," Impact Acceleration Stress, Publication 977, 61-67, National Academy of Sciences, National Research Council, 1962

147

Lissner, H. R., and F.G. Evans, "Engineering Aspects of Fractures," Clinical Orthopaedics 8:310-322, 1956.

ABSTRACT: The conclusion reached from the Stresscoat studies of deformation and fractures of the skull, the femur and the pelvis is that the various linear types of fractures all arise from failure of the bone as a result of tensile stresses within it. These stresses are created by any forces which tend to bend the bone, and the fractures always are initiated on the convex or tensile side of the particular area of the bone involved. Therefore, any mechanism which reduces or lessens forces tending to bend the long bones or the pelvis will consequently reduce the tendency for linear fractures of these regions.

The experiments of Rauber, Hulsen, and Dempster and Liddicoat all showed that the tensile strength of compact bone is considerably less than its compressive strength. Therefore, when a bone is subjected to both tension and compression stress it fails under tension. However, all fractures are not tensile failures. Compression fractures occur in the vertebral bodies and the calcaneum. All the various types of fractures experimentally produced could easily be duplicated by clinical fractures in the x-ray files of Detroit Receiving Hospital.

148

Lombard, C. F., "How Much Force Can the Body Withstand?" Aviation Week, 50:20-21, 23-25, 27-28, 17 January 1949.

149

Lombard, C. F., Human Tolerances to Forces Produced by Acceleration, Report No. ES-21072, Douglas Aircraft Company, Inc., El Segundo, Calif., 27 February 1948.

ABSTRACT: Human tolerance to acceleration is reviewed and discussed in a manner relatively free from medical terminology in an effort to make the current knowledge on the subject more usable. A chart is presented which shows on a log-log grid the approximate human tolerances to forces produced by acceleration in relation to velocity, stopping distance and time.

150

Lombard, C. F., "Can Change of Position Improve Ejection Tolerance?" J. Aviation Med., 28:209, (Abstract) April 1957.

ABSTRACT: The recommended position during ejection has been to have the spine oriented in the line of thrust of the ejection gun. Limits have been set upon the tolerance of the lumbar spine to take the load of the upper portion of the body under the G force imposed by ejection. This "ideal" position is not always achieved during escape with the use of the ejection seat. In certain instances successful escapes at high speed have been made when the occupant was bent forward so that the upper torso flexed downward to rest upon the legs. This suggests that an increased G load could be applied during the ejection stroke with the individual in this position. Such a position could result in higher velocities attained at the end of the stroke, resulting in better clearance of the tail of the aircraft, and permit at the same time a smaller configuration resulting in lower air drag.

151

Lombard, C. F., P. Close, F. C. Thiede, and F. Larmie, "Impact Tolerance of Guinea Pigs Related to Orientation and Containment," Aerospace Med., 35(1), January 1964.

ABSTRACT: This investigation indicates accelerations applied to guinea pigs at representative angles using selected methods of support and restraint at exposures of 53 to 99 g peaks for 3 to 4 milliseconds duration at 6,620 to 15,230 g/sec. onset are:

Survivable when applied transversely to the animal when in a uniform restraint device or a broad strap harness with a head restraint.

Frequently productive of serious or fatal injuries when applied longitudinal to long axis of animal's body, or at 45 degree angles, although the frequency of injury is greater in the former than in the latter positions.

Invariably productive of delayed reaction and death when applied in a ventral to dorsal direction without head restraint.

Areas of serious to fatal injuries are the spinal vertebral column, certral nervous system, the respiratory system, and the liver.

152

Lovelace, II, W. R., E. J. Baldes, and V. J. Wulff, The Ejection Seat for Emergency Escape from High-Speed Aircraft, Serial No. TSEAL-3-696-74C, Air Technical Service Command, Engr. Division, Army Air Forces, ASTIA ATI 7245, 31 August 1945.

ABSTRACT: This report presents data obtained from the German, British and Swedish Air Forces on the research and development of the pilot ejection seat and evaluates this information for application to the Army Air Forces pilot ejection seat program. It was found from tests that emergency escape from fighter aircraft, such as the P-38, P-51, P-47 and P-80, while traveling at high speeds is a difficult and dangerous operation. Emergency escape from high-speed bombers such as the A-26 is equally difficult. The ejection seat, as used operationally by the German Air Force, is the most successful method known to

date for emergency parachute escape from high-speed aircraft. The following design characteristics of the ejection seat assembly are believed desirable up to speeds of 550 miles per hour for AAF aircraft: (a) Maximum duration of acceleration: 0.1 second. (b) Maximum allowable average acceleration: 20 g with peaking to 25 g for 0.01 second or less, when ejecting the pilot above the aircraft. (c) Minimum allowable ejection velocity into wind stream: 57 ft./sec. in aircraft having a single vertical stabilizer of average height. (d) Minimum piston length: 30 inches, based on the above ejection velocity. In designing an ejection seat the following is required: (a) All parts of the body, especially the head, arms, and legs, must be supported. (b) A shoulder harness must be used, to prevent forward bending of the pilot with consequent fracture of the lower thoracic and lumbar vertebrae. (c) Arm rests must be used to reduce the load on the lower vertebral column.

153

Luchsinger, C. W., Additional Kinetic Measurements on a Pilot-Dummy Ejected from an F-82 Airplane, Engineering Division, Air Materiel Command, Wright-Patterson Air Force Base, Ohio, ASTIA ATI 63931, March 1949.

ABSTRACT: Five ejection seat tests, simulating pilot escape from high performance aircraft, were conducted with an F-82 twin engined fighter.

Kinetic measurement intelligence was successfully recorded during four of these tests by means of a recording oscillograph in conjunction with acceleration and strain gages. The pilot ejected the test seat, which was loaded with a 185 lb. anthropomorphous dummy, from the right cockpit by closing a switch on the control stick in the left cockpit. The normal maximum acceleration produced by the M-1 (Service) catapult was in the range of 15 g to 17 g units. Average ejection velocity was slightly less than the recommended 60 ft/sec. The drag coefficient of the seat and dummy is 1.56 at low Mach numbers, and has a percentage increase equal to that of a sphere with increase in Mach numbers.

154

Luchsinger, C. W., Kinetic Measurements During Pilot Ejection Seat Ground Tests - Appendices I and IX, Engineering Division, Air Materiel Command, Wright-Patterson Air Force Base, Ohio, ASTIA ATI 83 127, August 1950.

ABSTRACT: Kinetic qualities were measured during pilot ejection seat ground tests conducted with various centers of gravity of the ejected components and with various lengths of ejection rails. Sensing and recording of the kinetic quantities was accomplished by the use of resistance-bridge accelerometers, pressure transmitters and multichannel oscillograph, together with bridge balancing controls and appropriate connecting circuits. The normal maximum acceleration produced by the M-1 catapult was in the range of from 12 to 16 G units and the CG location had no consistent effect on the maximum peak value. As the CG was moved forward, the maximum ejection velocity tended to decrease in magnitude and a further decrease in magnitude was encountered when 28-in. ejection rails were used in lieu of the 32 7/8 in. ejection rails.

155

MacDonald, H. D., and N. J. Waecker, Development of Catapult Aircraft Ejection Seat, T20, WADD TR 59-306, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, FA Report R-1557, ASTIA AD 299 138, 1961.

ABSTRACT: Frankford Arsenal was requested to develop a rocket-assisted catapult that would provide sufficient impulse to accomplish safe low-altitude ejection. Two problems were considered during the program; first, attaining sufficient impulse with the rocket-catapult combination; and second, eliminating the bending of the catapult tubes during ejection. The first problem was solved by using a rocket motor attached to the bottom of the catapult. In this case, the rocket provides the sustained acceleration necessary to achieve the required final velocity. The problems associated with catapult tube bending in conventional catapults were eliminated by making the power stroke of the catapult section equal to the guided stroke of the seat in the rails. Flight stability and proper trajectory are obtained during ejection by angling the nozzle of the rocket so that the vector of the rocket thrust passes through the effective center of gravity of the seat-man mass and by igniting the rocket at the instant the rocket catapult is released from the aircraft structure. The T20 catapult is now ready for qualification and analysis testing.

156

Major Achievements in Biodynamics: Escape Physiology at the Air Force Missile Development Center, Holloman Air Force Base, New Mexico, 1953-1958, Air Force Missile Development Center, Holloman Air Force Base, N.M., ASTIA AD 201 282, 1958.

ABSTRACT: A detailed report of work done at Holloman Air Force Base between 1953-1958 on the following subjects: (1) deceleration and windblast experiments on the Holloman track; (2) specialized windblast studies; (3) other work on the escape problem; (4) seats and capsules (conflicting views of escape).

157

Martin, J., "Ejection from High Speed Aircraft," J. Royal Aeronaut. Soc. (London), 60(550):659-668, October 1956.

ABSTRACT: Early studies to determine physiological acceleration limits on a ground ejection rig and to test operational designs of the Martin-Baker aircraft

ejection seat in flight are described. The chief design features of the seat, including an automatic ejection device, main time release, ejection gun, leg restraining device, and duplex drogue system are described, and the peculiar conditions and methods of ejection at high altitude, high speed, and low altitude are discussed.

158

Martin, J., Report on Research and Development Carried Out by Martin-Baker Aircraft Co. Ltd. in Connection with Ejection Seats for High Speed Aircraft, Martin-Baker Aircraft Co., England, ASTIA ATI 89438, June 1949.

ABSTRACT: A description is given of British research and development carried out in connection with ejection seats and the escape of personnel from high-speed aircraft. The early history of the ejection seat project is presented as well as information on work done on the Defiant and Meteor III fighters. Development and construction of the Mark I seat and the fully automatic seat is discussed. A schedule of dummy and live ejections from the Meteor III is included. Photographs and drawings illustrate some of the equipment and graphs show acceleration data.

159

Mason, J. K., "Pathological Findings Following Unsuccessful Ejection from High Speed Aircraft," J. Forensic Med. (Johannesburg, S. Africa), 5(4):173-184, October-December 1958.

ABSTRACT: Operational and performance features of the standard British ejection seat are outlined. Post-mortem examinations of victims of unsuccessful escapes during flight are analyzed. The findings suggest human or instrumental failure in the preparatory stage or during actual ejection. Potential pathologic findings are correlated with various ejection stages. Illustrations are included showing how the post-mortem examination may disclose the circumstances surrounding the unsuccessful escape. On the basis of the degree of pulmonary fat embolism and of local reaction to injury, general observations are made with regard to timing of injuries. The role of post-mortem examinations in preventive medicine is stressed with particular regard to the uncommon causes of death encountered in unsuccessful ejections.

160

Matlock, H., E. A. Ripperger, J. W. Turnbow, and J. N. Thompson, High Velocity Impact Cushioning, Part I. Drop-Test Facilities and Instrumentation, Structural Mechanics Research Laboratory, University of Texas, Austin, Tex., ASTIA AD 220 737, August 1957.

ABSTRACT: Three drop-test installations were developed for research on impact cushioning. These range from a small indoor facility, 28 feet high, to a 275-foot tower which provides for both vertical and inclined guided drops of masses weighing up to 5000 pounds. Instrumentation measures time, force, and displacement during impact for determining energy-absorbing properties of materials and systems.

161

McCollom, I. N., and A. Chapanis, A Human Engineering Bibliography, Contract Nonr-126801, Tech. Rept. No. 15, San Diego State College, Calif., ASTIA AD 122 248, November 1956.

CONTENTS: General references, methods, facilities, and equipment
Man-machine systems
Visual problems
Auditory problems
Speech communication
Other sensory input channels
Comparison and interaction among sensory input channels
The design of controls and integration of controls with displays
Control systems
Design and layout of workplaces, equipment, and furniture
Body measurements and movements
High mental processes
Simulators and proficiency measuring devices
Environmental effects on human performance
- Behavioral efficiency, fatigue, and human capacities
- Operator characteristics for specific jobs

162

McCollom, I. N., Final Rept., A Human Engineering Bibliography, Contract Nonr-126801, San Diego State College, Calif., ASTIA AD 118 905, 1 December 1956.

ABSTRACT: Work involved in compiling a human-engineering guide for equipment design is outlined. Bibliographies, abstracts, translations, experimental studies, and special reports were prepared in the following areas: (1) comparison and interaction among sensory input channels (AD-95 131); (2) disorientation; (3) effect on human performance of acceleration, motion, and vibration; (4) effect on human performance of ventilation, temperature, and humidity; (5) man-machine integration (AD-106 677); (6) motion sickness (AD-95 139) and therapeutic drugs; (7) simulators and proficiency measuring devices; (8) speech communication; (9) systems considerations; and (10) work and fatigue (AD-95 133, AD-95 137). A special human-engineering bibliography of 5600 entries was assembled and published.

163

Millar, A., "Ejection Seats," Aircraft (Toronto), 18(4):16-18, 21; (5):33-34, 37, 84-85, April-May 1956.

ABSTRACT: The development of ejection seats and the initial experience dealing with ejection procedure are discussed. Flight experiments are reported and illustrated of dummy ejections using the automatic Martin-Baker seat. Consideration is given to the design of ejection seats, especially the Weber ejection seat, and to problems associated with downward supersonic ejection and capsule ejection. Mention is made of human ejection drills executed at low speeds. It is stressed that successful ejection always depends on the airman's psychological reactions.

164

Miller, B. P., "A Brief History of Emergency Escape," presented at Conference on Problems of Emergency Escape in High Speed Flight, Aircraft Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, ASTIA AD 14352, 29-30 September 1952.

ABSTRACT: This paper outlines the problems and history of aerial emergency escape. Appendix A is a Summary of Reports of Air Force Ejection Seat Bailouts during 1950 to 1952.

165

Miller, C. O., and J. A. Barton, Analysis of Ejections from Jet Fighter Aircraft, Report 11184, Chance Vought Aircraft, Inc., Dallas, Tex., 7 October 1957.

ABSTRACT: This report includes analyses of over 1100 ejections with respect to altitude, airspeed, aircraft attitude, cause, injury, opportunity and probability to decelerate prior to ejection, and predictions of future experience with automatic equipment and ground level systems. Recommendations concerning escape systems are also included.

166

Miller, C. O., Synthesis of Impact Acceleration Technology for Aviation Crash Injury Prevention (Project SIAT), Trecom TR 63-31A, U.S. Army Transportation Research Command, Fort Eustis, Va., June 1963.

ABSTRACT: This report was prepared by Flight Safety Foundation, Inc., New York, New York. It describes a project to search for and collate information on the topics of (1) Hazard Exposure to Impact Acceleration, (2) Crash Loads, (3)

Design for Impact Acceleration, (4) Test and Analysis Methodology, and (5) Human Tolerance to Impact Acceleration. An information retrieval system utilizing IBM cards is detailed and code indexes provided.

167

Mohler, S. R., A. H. Schwictenberg, and E. Blick, Crash Injury Analysis of X-15 Inverted Impact, Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma-Lovelace Foundation, Albuquerque, N.M., and University of Oklahoma, Norman, Okla.

ABSTRACT: On November 9, 1962, the X-15-2 rolled over after touchdown following what was flight 31 at Edwards Air Force Base. The pilot, Mr. John B. McKay, jettisoned the canopy when the rollover became imminent. When the forward fuselage of the inverted X-15 struck the ground, the pilot received near fatal impact forces in the longitudinal axis of his body, headward to footward ($-G_z$).

By virtue of the complex accelerometer and attitude instrumentation installed in the X-15 the quantitative dynamics of the events associated with the crash have been determined. In addition, detailed pre- and post-accident medical assessments of the pilot are available, including critical roentgenograms of the spine.

Following the accident, the pilot was two centimeters shorter in height, a result of compression fractures of five thoracic vertebrae (T-3, T-4, T-5, T-6, and T-7). Also, a loss of vital capacity occurred (from 4.87 liters to 4.06 liters) due to the post-accident kyphotic change. The soft tissue injuries included the production of an inguinal hernia.

In view of the fact that data concerning the survival tolerance to impacts in the (G_z) axis are scarce and fragmentary, this accident, with its associated instrumentation, enables us to accurately pinpoint the forces involved and correlate these with the injuries. An analysis of the tracings at the pilot's seat reveals that the ($-G_z$) velocity at the time of impact was 13.7 feet/second, and that deceleration in this axis occurred during 10 milliseconds, giving approximately 42 g during this period.

Since this uniquely instrumented aircraft was involved in an accident that imposed headward to footward forces on the pilot which were considerably above the fail points for vertebral compression, but were just below the fatal injury level for separation of the heart from the inferior vena cava, additonal biomedical impact data are available for completing the "Tables of Human Tolerance of Impacts." Additional aspects of the accident will be discussed including the implications for crash-safety design. Mr. McKay has returned to full flying status.

168

Mohrlock, H. F., Jr., "Aircraft Performance Systems Related to Escape Systems", J. Aviation Med., 28:59-64, February 1957.

ABSTRACT: Many variables influence crew escape from military aircraft. The first item considered is aircraft speed capability. Altitude, here, is an important variable. Improved escape systems are necessary to keep peak deceleration within human tolerance at speeds beyond 600 knots. Several ways are proposed in which this may be accomplished. First, reduce the drag of the seat relative to its ejectable weight. A second measure would be to add seat thrust in the direction of flight. A third improvement might be that of an escape capsule. Aircraft altitude capabilities are a second important consideration.

The goal of the design engineer should be a system that will provide a means of safe escape at any speed and altitude which an aircraft is capable of attaining without airframe failure. It is imperative that such a system be designed for the entire flight performance capabilities of the aircraft. A successful escape system consists of more than the ejection seat or capsule. It is an integration of the man with his clothing, oxygen and pressure supply, body restraints, survival gear, and stabilizing and descent parachutes to provide protection against sudden decompression, deceleration, acceleration, wind blast, thermal changes, and a hostile environment which might exist upon landing.

169

Montagard, F., "Systematic X-Ray Examination of the Spinal Column before Entering Ejection Seat Training (Examen radiologique systematique de la colonne vertebrale avant stage d'entrainement an siege ejectable)," Rev. Med. Aero (Paris), 8(3):243-248, 1953.

ABSTRACT: X-ray examination of the spinal column of fighter pilots to be trained in the use of ejection seats has the triple purpose to detect diseases of the bone, traumatic lesions or their sequelae, and anomalies of the spinal column and body structure in general. This article is primarily concerned with the latter aspect, especially with the timely detection of disorders of the equilibrium or of a slipped disk. The standing position was standard for the spinal X-ray examination, but a few pictures were also taken in the ventral position. In the majority of the cases the spinal column showed no abnormalities. Among the pathological conditions detected, the most interesting were: a case of flattening of two vertebrae, agenesia of the disk of the second and third cervical vertebrae, and bilateral spondylolysis of the posterior arc of the fourth and fifth lumbar vertebrae. Spinal malformations are not always indicative of elimination from ejection-seat training; however, anomalies of the lower lumbar column have to be watched carefully.

170

Montagard, F., and R. Papet, "Lumbar Difficulties from the Ejection Seat and the Training Ramp (Incidents Lombaires du Siege Ejectable et de la Rampe d' Entrainement). Reflections Apropos of Systematic Radiography of the Vertebral Column (Reflexions a propos de la Radiographie Systematique de la Colonne Vertebrale)," Rev. Med. Aero (Paris), 14:377-383, 1959.

171

Montagard, F., and R. Picamoles, "1500 Systematic Radiographs of the Lumbar Spinal Column to Test Ejection Seat Capacity (1500 Radiographies Systematiques de la Colonne Lombaire pour Aptitude au Siege Ejectable)," Rev. Med. Aero (Paris), 11(1):56-69, 1956.

ABSTRACT: Radiological examinations were conducted in 1552 French airmen to detect the presence of spinal anomalies which might increase the probability of injury during ejection. Minor malformations of the spine, including sacralization and spina bifida, were observed in 30% of the men, but were not considered dangerous. Malformations for which ejection-seat training was considered inadvisable were observed in almost 4% of the men and included spondylolisthesis (2.32%), intervertebral hernias, and vertebral osetochondrosis.

172

Morrow, C. T., and R. B. Muchmore, "Shortcomings of Present Methods of Measuring and Simulating Vibration Environments," J. App. Mech., pp. 367-371, September 1955.

173

Moseley, H. G., "U.S. Air Force Experience with Ejection Seat Escape (Problems of Escape from High Performance Aircraft: A Symposium)," J. Aviation Med., 28(1):69-73, 1957.

ABSTRACT: Escape from high performance aircraft by use of the ejection seat to date has been attended with an incidence of 23 per cent fatalities and 14 per cent major injuries. The great majority of ejection attempts were at medium and low altitudes and medium and low speeds. The outstanding cause of fatalities has been inability to separate from the seat and deploy the parachute prior to striking the ground when ejection was attempted at low altitudes, particularly when the aircraft was out of control or in a dive. Airspeed has had little effect upon the outcome, with the exception that ejection attempts at or near the speed of sound may be attended with incapacitating results of deceleration with the type of seat now being

used. It is concluded that if the fatality rate is to be lowered, there must be improved provisions for escape at low altitudes and low speeds where the great majority of emergencies occur, and that if escape at supersonic speeds is to be successful, the effects of deceleration and other phenomena must be mitigated.

174

Moseley, H. G., and R. H. Shannon, USAF Ejection Escape Experience, 29 August 1949 through 30 June 1958, Rept. M-12-58, USAF, Directorate of Flight Safety Research, Norton Air Force Base, Calif., ASTIA AD 207 207 November 1958.

ABSTRACT: This study analyzes 1,462 United States Air Force ejection seat emergency escapes from the period 29 August 1949 through 30 June 1958. Results to personnel are studied in relation to altitude, airspeed, altitude, availability and use of automatic equipment, and other pertinent factors. Problem areas associated with ejection escape from high performance aircraft were sought although few cases of attempted escape at supersonic speeds were available. Recommendations designed to reduce the incidence of unsuccessful (fatal) ejections are made in the areas of 1) operations and training, and 2) research and development.

175

Moseley, H. G., USAF Operational Experience with Escape from High Performance Aircraft. Period: 29 August 1949 through 31 May 1956, Publication M-24-56, Directorate of Flight Safety Research, Norton Air Force Base, Calif., ASTIA AD 125069, 15 September 1956.

ABSTRACT: As of 30 June 1956, emergency escape from high performance aircraft by use of the ejection seat was resorted to in the U.S. Air Force on 877 known occasions. 678 of these ejections (77%) were successful in saving the life of the pilot. Since conventional bailouts would have been extremely difficult or impossible in the majority of instances, the ejection seat has thus demonstrated commendable life saving capabilities. However, there was sufficient major and fatal injury in these escape attempts to warrant considerable aeromedical and design concern. The results of use of the ejection seat, regarding injury fatalities, are tabulated.

176

Neely, S. E., and R. H. Shannon, Vertebral Fractures Among USAF Aircraft Accident Survivors, Rept. M-4-58, USAF, Directorate of Flight Safety Research, Norton Air Force Base, Calif., 25 February 1958.

177

Neely, S. E., and R. H. Shannon, "Vertebral Fractures in Survivors of Aircraft Accidents," J. Aviation Med., 29(10):750-753, October 1958.

ABSTRACT: In summary, vertebral fractures are a significant problem in the medical management of aircraft accident survivors. The responsible medical officer should be prepared to recognize and handle this type of injury. Because the rate of these injuries is increasing, improved methods of restraint and protection for the vertebral column must be found.

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Nickerson, J. L., and R. R. Coermann, Internal Body Movements Resulting from Externally Applied Sinusoidal Forces, Rept. No. AMRL-TDR-62-81, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio, July 1962.

ABSTRACT: This report contains a description of an X-ray device designed to permit the observation of the movement of internal structures in the animal body subjected to sinusoidal oscillations. From the X-rays taken by this device, it has been possible to determine the resonance frequency and phase shift of regions within the abdomen and thorax set in motion by external oscillatory forces. The results of observations made on anesthetized dogs show that the visceral content of the abdomen and thorax appears to oscillate as a mass having a resonant frequency of 3 to 5 cycles per second and with damping of one-fifth to one-quarter of the critical value.

179

Operational Experience with Ejection Escape Systems from 1 January 1949 through 31 December 1954, Publication No. 23-55, Directorate of Flight Safety Research, Norton Air Force Base, ASTIA AD 72 809, 1 August 1955.

ABSTRACT: During the period 1 January 1949 through 31 December 1954, reports of 518 ejection escapes from USAF aircraft were received. Successful escape has been made from aircraft in various attitudes, at altitudes from 500 to 38,000 feet, and at airspeeds up to 560 knots indicated. The percentage of fatal injuries has gradually decreased from a high of 27 per cent in 1951 to 21 per cent in 1954. Violent contact with the ground as a result of ejecting too low has been the major cause of ejection fatalities. During 1954, the percentage of fatal injuries during ejections initiated below 3000 feet declined considerably over previous years. Wider use of the automatic opening lap belt and automatic opening parachute, and provisions for ejecting through the canopy are considered to be partially responsible for this improvement. In addition, the recommended procedure of unfastening the manual type lap belt prior to ejecting below 2000 feet when position can be maintained in the seat, is partially responsible for the decrease in fatalities. It is still apparent, however, that some personnel, particularly those in high speed dives and uncontrollable maneuvers are delaying ejection until they reach too low an altitude. In addition to fatal injuries during ejection, two other areas of major concern are revealed by this study: accidental and premature ejections, (52 cases) and instances in which personnel were unable to eject because of canopy or ejection seat difficulties (105 cases). Improvement in these areas and a decrease in the percentage of fatal ejections are possible through better design, maintenance, inspection and crew training on ejection escape systems. Aircrew training should place greater emphasis on the altitude at which ejection escape should be initiated.

180

Patrick, L. M., "Caudo-Cephalad Static and Dynamic Injuries to the Vertebrae," presented at the Fifth Stapp Automotive Crash and Field Demonstration Conference, University of Minnesota, September 1961.

ABSTRACT:

1. Forces to the lumbar vertebrae are a linear function of caudo-cephalad acceleration up to the point where buckling or fracture takes place. Linear results have been noted up to 15 g's.

2. High rates of onset produce high peaks of strain of short duration. A rate of onset of 1760 g's per second resulted in a two cycle surge of strain in the third cervical vertebrae with a magnitude four times that of the steady state strain. There was no strain surge at low rates of onset.

3. Strain in the cervical vertebrae from acceleration was nine times greater with the head free than when it was fully restrained.

4. End plate fractures occurred in the lumbar vertebrae at loads as low as 435 pounds. Muscle loads will reduce the external loads required to fracture the end plates still further.

5. Vertebral end plate fractures are very difficult to find by X-ray examination.

6. Protection of automobile passengers from injury is basically more difficult than the protection of airplane passengers. Reason: accelerations encountered in automotive crashes are greater even though the speeds are much lower.

181

Payne, C. F., and R. A. Bosee, Study of Physiological Stresses with Ejection Loads: The Mechanism and Cause of Crash Landing and Ejection Vertebral Injuries in U.S. Naval Aviation, Report No. NAEC-ACEL-467, Air Crew Equipment Lab, Naval Air Material Center, Philadelphia, Pa., ASTIA AD 409465L, 8 July 1963.

ABSTRACT: The basic mechanism responsible for the production of crash landing and ejection vertebral injuries is the concentration of inertial and restraint force components on the front of the vertebrae by spinal flexion. Restraint of the upper body by the conventional system adds to the loading of the vertebral column to such an extent that the compression force on the vertebrae greatly exceeds the inertial force of the upper body. Thus, with an ejection acceleration or crash landing impact of 18 g, the compression force may be equivalent to the inertial force on the upper body of a 30 or 40 g acceleration. Restraint of the upper body by a harness of a proposed configuration does not add to vertebral loading; rather, in providing restraint, some support is given so that acceleration tolerance of the vertebral column is increased to above normal limits.

182

Payne, C. F., and R. A. Bosee, "The Mechanism and Cause of Vertebral Injuries Sustained on Ejection from U.S. Naval Aircraft," presented at the 33rd Annual Meeting of the Aerospace Medical Association, Atlantic City, N.J., 9-12 April 1962.

ABSTRACT: Considering the available evidence, the basic mechanism responsible for the high incidence of vertebral injury on ejection from U.S. Naval aircraft is the concentration of inertial and restraint force components on the front of the vertebrae by spinal flexion. Flexion occurs because of poor positioning, lack of support, and inadequate restraint of the body. Until further improvements are made in these areas and spinal flexion kept to a minimum, it will not be possible to subject the body to its potentially tolerable limit of ejection acceleration without perpetuating the high incidence of vertebral injury.

183

Payne, P. R., "An Analog Computer Which Determines Human Tolerance to Acceleration," Impact Acceleration Stress, Publication No. 977, 271-300, National Academy of Sciences, National Research Council, 1962.

ABSTRACT: The purpose of this paper is to describe and demonstrate a small analog computer which is designed to show the physiological effect of short period acceleration on man. An arbitrary acceleration-time history can be set up on the front of the computer by "plotting" a graph with sliding beads. Calibrated dials enable the dynamic characteristics of the restraint system to be specified (such as cushion thickness, stiffness and damping, for example), and the computer can then be started. A meter reads out the peak value of the "Physiological Index," which is an arbitrary numerical scale.

An analog of this type is only as good as the experimental data upon which its analogy is based. But within this limitation it can be used for five functions. The paper concludes with a description of possible future developments, and particularly the inclusion of non-linear terms and the long period acceleration tolerance limits established in centrifuge testing.

184

Payne, P. R., "Optimizations of Human Restraint Systems for Short-Period Acceleration," Publication No. 63-WA-277, American Society of Mechanical Engineers, 1963.

ABSTRACT: A restraint system's main function is to restrain its occupant when his vehicle is subjected to acceleration. If the restraint system is rigid and well-fitting (to eliminate slack) then it will transmit the vehicle acceleration to its occupant without modifying it in any way. Few present-day restraint systems are stiff enough to give this one-to-one transmission characteristic, and depending upon their dynamic characteristics and the nature of the vehicle's acceleration-time history, they will either magnify or attenuate the acceleration. Obviously an optimum restraint system will give maximum attenuation of an input acceleration. In the general case of an arbitrary acceleration input, a computer must be used to determine the optimum dynamic characteristics for the restraint system. Analytical solutions can be obtained for certain simple cases, however, and these cases are considered in this paper, after the concept of dynamic models of the human body is introduced. The paper concludes with a description of an analog computer specially developed for the Air Force to handle completely general mechanical restraint optimization programs of this type, where the acceleration input may be any arbitrary function of time.

185

Payne, P. R., "The Dynamics of Human Restraint Systems," Impact Acceleration Stress, Publication No. 977, 195-257, National Academy of Sciences, National Research Council, 1962.

ABSTRACT: A man who is sitting directly upon the pan of an ejection seat may suffer no ill-effects from the spinal acceleration imposed upon him by the thrust of the catapult during ejection; yet when we make him more comfortable by giving him a cushion to sit on, the same catapult acceleration may break his back.

Acceleration is most logically divided into three distinct regimes, from a physiological point of view.

In an <u>impact acceleration</u>, where velocity change is the important criterion, a cushion or any other resiliency in series with the man is always beneficial, in that it reduces the physiological effect of the shock.

In a <u>short period acceleration</u>, which may be roughly defined as having a duration of less than one second, the effect of the restraint system may be either harmful or beneficial, depending upon its dynamic characteristics.

For <u>long period accelerations</u>, where "hydraulic" limitations predominate, restraint dynamics are of no importance, and we are concerned primarily with adequate support.

In the case of impact accelerations, the only parameter of importance is the total energy which the restraint system can absorb before bottoming, so that a pure spring could yield as great an attenuation as a visco-elastic cushion. But for short period accelerations, both damping and "bottoming depth" assume enormous importance, whilst the energy absorbing capability becomes relatively unimportant.

Although some simple generalizations can be deduced from closed form solutions to analytically simple acceleration input histories, an analog computer must be used to determine the optimum restraint dynamics for minimum physiological effect from the irregular accelerations usually experienced in practice. Since a restraint system is merely a damped spring system, in the normal engineering sense, it is obviously both more accurate and far less expensive to determine the optimum parameters by this means, however. To try to determine even optimum cushion characteristics by experimental means is almost impossible, unless we are concerned with a relatively fixed acceleration time history, such as the thrust of an ejection seat catapult.

Considerable gains from these techniques are seen for the future, in that we can hope to reduce the physiological shock of accelerations imposed by existing vehicles and escape systems, by means of relatively simple changes in the restraint systems. It is quite possible that the materials currently used -- in cushions for example -- are nowhere near the true optimum, and that quite dramatic improvements can be obtained.

Secondly, many physiological tests will be wasted, or at least less useful than they might be unless we have a reliable means of correcting for the different restraint systems used.

186

Payne, P. R., "The Mathematical Theory of Restraint System Dynamics," Frost Engineering Development Corporation, Englewood, Colo., January 1963.

187

Pearson, R. G., Injury Severity as Related to Seat Tie-Down and Belt Failure in Lightplane Accidents, TREC Technical Report 61-96, Aviation Crash Injury Research, Phoenix, Ariz., ASTIA AD 265092L, August 1961.

ABSTRACT: The purpose of this study was to evaluate the relationship between tie-down effectiveness and injuries sustained in 1,025 occupants of lightplanes involved in ground-object collisions, or in spin-stall crashes. Critical injuries to the head and upper torso were found to occur even though there was adequate seat belt restraint. In approximately one-third of the 1,025 cases either seat failure or belt failure, or both, occurred. Belt failure occurred more frequently than seat failure, yet injury severity was greater when seats failed than when belts failed. The need for additional safety measures is emphasized by the findings.

188

Perey, O., "Biomechanical Problems of the Lumbar Spine," Impact Acceleration Stress, Publication No. 977, 25-26, National Academy of Sciences, National Research Council, 1962.

189

Perey, O., "Fracture of the Vertebral End-Plate in the Lumbar Spine, an Experimental Biomechanical Investigation," Acta Ortho. Scand., Supplement 25, 1957.

Experimental investigations, mainly of a biomechanical nature, have been carried out to establish the nature of the reaction of lumbar vertebrae and their discs to forces applied for different lengths of time.

The first section deals with specimens consisting of two vertebra and the intervening disc which were subjected to a strong force during a short period of time. Stress was established within the specimens at right-angles to their cross-sectional dimension. The spaces within the discs have been radiologically visualized by the injection of a contrast medium (discography). Four experimental series were made in which the maximum forces were calculated to be 1050, 1200, 1250, and 1350 kp during approximately 0.006 sec. A total of seventy-six experiments were carried out and the course of events followed radiologically, in some instances by Roentgen plates made at a rate of forty-eight per second and in others, by still plates in conjunction with an image-amplifier.

In no instance did the contrast medium change its position except when simultaneous damage to the vertebral body occurred.

An existing disc herniation was enlarged in one instance.

Compression fractures of the vertebral body occurred in six instances (8%).

Fracture of the end-plate occurred in twenty instances (26%). These fractures could be divided into three different types—fractures situated centrally in the end-plate, fractures situated so far peripherally that a portion of the vertebral body was dislodged, and fractures producing transverse fissures extending through the entire end-plate.

These fractures could not always be detected on routine Roentgen plates. Contrast medium was helpful in every instance. Some specimens were tomographed and the end-plate fractures could also be detected by this radiological method.

The second section is concerned with the application of static force. Two series of experiments were carried out using specimens consisting of two lumbar vertebrae and the intervening disc and specimens of three lumbar vertebrae with the intervening discs. In some instances the twelfth thoracic vertebrae was included in the specimens.

Forty specimens were used in the experimental series on two vertebrae. These were compressed until the breaking-point was reached. The values obtained for the breaking-point varied with age. For the group "over sixty", the average was 425 kp with a range of 290 to 530 kp. The average for the group "under forty" was 780 kp with a range of 510 to 1100 kp. Microscopically visible end-plate fractures occurred in thirteen instances or 32%. When the specimens were classified according to age and the vertebral body which was fractured, it was found that twelve end-plate fractures occurred among the eighteen experiments (67%) carried out on specimens which included the vertebral bodies from Th_{12} to L_3 from individuals under sixty years of age.

Twenty-four specimens were used in the experimental series using three vertebrae. End-plate fractures occurred in ten instances or 42%. In two of these ten experiments, two end-plate fractures were obtained in the same specimen. The end-plates bordered onto different discs.

Discography was not carried out in the experiments using static force and the Roentgen plates were not made from exactly the same positions before and after the application of force. Of the ten end-plate fractures which occurred, it was possible to establish the diagnosis radiologically in only four instances.

In the third section it was found that the breaking-point for the lumbar vertebrae shows great individual as well as age variations. Eight-one vertebrae were examined and the average for the group under sixty was 600 kp and over sixty, 260 kp.

The resistance of the central, lateral, and ventral portions of normal end-plates showed no statistical differences in measurements made on eighty-one vertebrae. The resistance of the end-plate centrally was examined on two hundred and twenty-three vertebrae. Individual variations were great. A distinct decrease in resistance was associated with increasing age.

Average values for the age groups

20—30 years	. . . .	107 kp
31—40 "	. . . .	98 "
41—50 "	. . . .	76 "
51—60 "	. . . .	77 "
over 60 "	. . . .	43 "

The surface area of the end-plates of one hundred and eighty-eight lumbar vertebrae was calculated and gave the following average values:

L_1	. . . .	14.3 cm^2
L_2	. . . .	15.8 "
L_3	. . . .	16.3 "
L_4	. . . .	17.8 "
L_5	. . . .	18.0 "

A normal nucleus in a mature individual occupies twenty-six per cent of the entire surface on the average.

In the fourth section, the hypothesis that the central end-plate fractures occur as the result of an increase of pressure within the disc is developed mathematically.

The fifth section, deals with such practical problems as ejection in a catapult seat from an aircraft. The maximum allowable values for the acceleration of the seat had been calculated earlier on the basis of empirical observations. A curve expressing force in relationship to duration of acceleration has been drawn using the values obtained in the experiments on dynamic and static force. A detailed knowledge of similar curves for glass and metals served as a basis for the construction of this curve.

190

Perry, D. R., and L. C. Dyer, Incidence, Nature, and Extent of Injury in Crash Landings and Bailouts, Artic Aeromedical Lab., Ladd Air Force Base, Alaska, ASTIA AD 116239, 1956.

ABSTRACT: Data were analyzed to establish the effects of terrain, weather, and type of aircraft upon the number and extent of injuries in crash landings and bailouts. Based on data obtained from a worldwide survey of major airplane accidents, the rate of fatal or major injury in swampy terrain is 3.4% for a bailout and zero for a crash landing. For flat farmland, the probability of a fatal or major injury for either a bailout or a crash landing is about 2 out of 10 persons. For desert terrain the probability of fatal or major injuries in a bailout is 2 out of 10 as compared to 1 out of 10 in a crash landing. For terrain consisting of small hills, the probability of a fatal or major injury is 1 in 10 for bailouts and 3 in 10 for a crash landing. For a crash landing in wooded areas, the probability of fatal or major

injury is 9 out of 10. In mountainous terrain, the indicated probability of fatal or major injuries is 2 out of 10 for a bailout and 6 out of 10 for a crash landing. The probability of fatal or major injury when crash landing in open water is 6 out of 10 as compared to 3 out of 10 for a bailout. Major accidents occurring in Arctic regions are studied with reference to bomber- and jet-type aircraft, jet fighters, trainer aircraft, and all other aircraft. A total of 33 persons were involved in bomber crash landings, of which 6.1% were fatalities. For cargo aircraft, 21.7% of bailouts were fatal, and 17.4% of the crash landings were fatal. Bailouts from jets resulted in 23.1% fatalities. Crash landings involved 28.6% fatalities. No fatalities were reported from trainer aircraft. All other types of aircraft involved 4 fatal injuries.

191

"Pilot Ejection Seat being Tested at Supersonic Speeds to Determine Its Limitations," Technical Data Digest, 15(3):9, March 1950.

ABSTRACT: To find out the speed limitations of the currently used USAF pilot ejection seat, AmC-Northrop Aircraft engineers have created a system which propels an F-89 ejection seat along a track at speeds up to 1100 mph.

192

Pletcher, K. E., and S. E. Neely, "USAF Emergency Escape Experience -- 1950-1959," Aerospace Med., 32(6):524-534, June 1961.

ABSTRACT: Ten years' experience of escape from USAF tactical aircraft are reviewed in an effort to establish the actual hazards connected with emergency escape as opposed to those which experience has shown to be of less importance than the amount of attention they have received. The analysis makes use of tables and graphs to show major accident figures for the period under study, the role of escape in fatal accidents, the effect of ejection seat on escape statistics, type of emergency precipitating ejection, amount of terrain clearance, aircraft attitude, difficulties initiating ejection and after egress, water landing, and survival after ejection. Two new developments in escape are discussed: rocket catapults and capsules.

193

Poppen, J. R., "High Acceleration of Short Duration," Military Surg., 103(1): 30-32, July 1948.

ABSTRACT: A brief outline of the historical background of acceleration studies is given, starting with the early work of the Germans in 1939, discussing the advances of the British during World War II and the postwar work continued here in the United States.

194

Poppen, J. R., "Introduction and History of the Aircraft Escape Problem," J. Aviation Med., 28(1):57-59, February 1957.

ABSTRACT: A short history is given of aviation escape mechanisms and associated problems, from the parachute of World War I through the ejection mechanisms of today's supersonic aircraft. This is followed by a brief introduction of each of the symposium's sub-topics and their authors.

195

Poppen, J. R., Notes on Study of Back Injuries in Case of Nose Gear Failures, Memo No. EM-364, Enclosure 8, Rept. E-553, Chance-Vought Aircraft, Inc., Dallas, Tex., 1 February 1956.

ABSTRACT: The forces causing spinal fracture are the sum of those existing in the airplane plus those developed in the body as a result of forward and downward movement of the upper part of the body. Both must be reduced or eliminated to prevent injuries. Prevention of nose gear failure and improvement of the upper body restraint system are suggested as solutions to the problem of spinal injury.

196

Poppen, J. R., "Support of Upper Body Against Accelerative Forces in Aircraft," J. Aviation Med., 29(1):76-84, January 1958.

ABSTRACT: There is increasing need for the direct support of the upper part of the aviator's body against increasing vertical forces. In a study of the mechanical support and mass distribution of the upper part of the body, principles are determined to be applied in the design of personal equipment to accomplish this support. The objectives are (1) the reduction of dynamic response between the upper and lower masses to lower the compressive impact loads on the lumbar spine, and (2) the use of greater thrust, higher velocities and higher trajectories in upward ejection seats. Certain preliminary tests are reported which confirm the validity of the principles defined and give promise that effective means of providing the desired support can be foreseen.

197

Preece, C. D., "Bang! Are You Alive?," Air Clues, 14(6):176-180, March 1960.

ABSTRACT: Between January 1, 1953, and August 31, 1959, 168 RAF personnel ejected, and of these 130 were successful.

The main purpose of this letter is not to analyze the unsuccessful cases, but to pose a question. Are aircrew given, and do they give themselves, a fair chance when the occasion demands that they reach for the handle?

198

"Preliminary Report on a Substantiated Supersonic Ejection," Mitchell Air Force Base, N. Y., Med. Training Bull., 3(3):1-7, February 1956.

199

"Problems of Pilot Ejection," The Aeroplane, 80(2071):378-379, 30 March 1951.

ABSTRACT: Summary of lecture before Roy. Aero. Soc. on physiological aspects, trajectory and control problems of ejection-seats, which requirements are to be fulfilled.

200

Purkey, G. F., Acceleration and Velocity Measurements Obtained during Pilot-Dummy Ejection from a TF-80C Airplane, Memo Report MCREXA3-45341-4-2, Wright-Patterson Air Force Base, Ohio, ASTIA AD 65040, 1 September 1949.

ABSTRACT: A report of the accelerations and velocities relative to the forces acting on a pilot-dummy ejected upward from high performance aircraft by means of a catapult. Appendix I is entitled, The Principal, Calibration, Installation, and Flight Operation of the Acceleration Recording Equipment. Appendix II presents a table and three graphs of ejection accelerations and velocities.

201

Richter, H., "Ejection Experiments with the Catapult Seat," The Ejection Seat for Emergency Escape from High Speed Aircraft, Appendix 2, ASTIA ATI 7245, 1945.

ABSTRACT: Following upon the ejection experiments with sandbags, ejections of human subjects were undertaken with the cooperation of Professor Wacholder of the Physiological Institute, University of Rostock, and his assistant, Doctor Aeffner. We made two experiments with Mr. Voss (VSA) and Mr. Wegner (Statik); both subjects were ejected, the first at 12 and the second at 10 g. In each case electrocardiograms were recorded with electrodes on the right and left wrists. The procedure was first to record the heart beat before ejection, then during ejection, and finally once again some time after the completion of the ejection. The electrocardiograms obtained are recorded in Figure 5. Here, having discussed the matter with Professor Wacholder, I wish to bring together a statement of all the processes which might cause injuries of any kind to experimental subjects in this work: 1) Compression fractures of the spinal column; 2) Concussion of the central nervous system, especially with contrecoup symptoms of the type seen in concussion of the brain, 3) Hemostatic effects; 4) Disturbances in the inner ear (labyrinth).

202

Roaf, R., "A Study of the Mechanics of Spinal Injuries," J. Bone Joint Surg., 42B(4):810-823, November 1960.

ABSTRACT:

1. Compression forces are mainly absorbed by the vertebral body. The nucleus pulposus, being liquid, is incompressible. The tense annulus bulges very little. On compression the vertebral end-plate bulges and blood is forced out of the cancellous bone of the vertebral body into the perivertebral sinuses. This appears to be the normal energy-dissipating mechanism on compression.

2. The normal disc is very resistant to compression. The nucleus pulposus does not alter in shape or position on compression or flexion. It plays no active part in producing a disc prolapse. On compression the vertebral body always breaks before the normal disc gives way. The vertebral end-plate bulges and then breaks, leading to a vertical fracture. If the nucleus pulposus has lost its turgor there is abnormal mobility between the vertebral bodies. On very gentle compression or flexion movement the annulus protrudes on the concave aspect—not on the convex side as has been supposed.

3. Disc prolapse consists primarily of annulus; it occurs only if the nucleus pulposus has lost its turgor. It then occurs very easily as the annulus now bulges like a flat tire.

4. I have never succeeded in producing rupture of normal spinal ligaments by hyperextension or hyperflexion. Before rupture occurs the bone sustains a compression fracture. On the other hand horizontal shear, and particularly rotation forces, can easily cause ligamentous rupture and dislocation.

5. A combination of rotation and compression can produce almost every variety of spinal injury. In the cervical region subluxation with spontaneous reduction can be easily produced by rotation. If disc turgor is impaired this may occur with an intact anterior longitudinal ligament and explains those cases of tetraplegia without radiological changes or a torn anterior longitudinal ligament. The anterior longitudinal ligament can easily be ruptured by a rotation force and in my experience in so-called hyperextension and hyperflexion injuries are really rotation injuries.

6. Hyperflexion of the cervical spine or upper thoracic spine is an anatomical impossibility. In all spinal dislocations a body fracture may or may not occur with the dislocation, depending upon the degree of associated compression. In general, rotation forces produce dislocations, whereas compression forces produce fractures.

203

"Rocket-Propelled Ejector Seat," Engineering (London), 182(4734):691, 30 November 1956.

ABSTRACT: A rocket-propelled ejector seat is briefly described, designed to permit pilots of Convair TF-102A combat trainer aircraft to escape safely even at emergencies near ground level. The new Rescu Mark 1 seat combines a normal cartridge-actuated catapult with a rocket incorporated in th inner tube and brought into action by the cartridge catapult. Comparative tests with a standard M3 cartridge-actuated ejector seat indicate that rocket-propelled escape systems ensure greater clearance from the aircraft, a reduction in the deceleration rate as the man-seat mass is catapulted in the air, and a greatly increased "on-the-deck" escape probability.

204

Roos, C. A., "Bibliography of Space Medicine," U.S. Armed Forces Med. J., 10(2):172-217, February 1959.

ABSTRACT: This compilation of 446 references covers aspects of space medicine such as sealed cabin problems, acceleration and deceleration, fractional and zero gravity, cosmic radiation, nutrition in space flight, survival problems, psychological and social problems, ground crew problems, and extraterrestrial aspects. Entries are arranged chronologically starting with 1958 and going back as far as 1928.

205

Roxburgh, H. L., "Biological Problems of Escape at High Altitudes," In Bergeret, P., Escape and Survival: Clinical and Biological Problems in Aero Space Medicine, Pergamon Press, N.Y., pp. 1-4, AGARDograph 52, ASTIA AD 261881, 1961.

ABSTRACT: The experimental works on evacuation at high altitudes are difficult to perform because constraints are brought into play which cannot be combined when they are simulated on the ground, and which in the air, are too costly.

Separately, these constraints are studied, but though one disposes of numerous known physiological facts concerning the reaction of the organism, our knowledge in this domain retains some gaps. These constraints are briefly reviewed and the most complex experience to date, an evacuation below 50,000 feet (15,000 meters), is described.

The problems of evacuation in the future are also evoqued.

206

Ruff, S., "Brief Acceleration: Less Than One Second," German Aviation Medicine, World War II, Chapter VI-C, Vol. I, pp. 584-597, U.S. Government Printing Office, Washington, D.C., 1950.

ABSTRACT: The discussion of the general problems of human tolerance to shock-like accelerations leads to an outline of the physical quantities which determine the limits of tolerance: 1. peak acceleration, 2. time of exposure to acceleration, 3. the momentum, 4. the increase of acceleration with time, the jolt, or the 3rd derivative of distance with respect to time, and 5. the nature of the inertial forces and their point of application to the body.

Testing facilities and investigations are described including tolerance to acceleration under varying restraint and force application conditions, determination of compressive breaking strength of individual vertebral bodies, investigation of the ability of the spinal column to absorb energy, determination of the percentage of total body weight supported by individual vertebrae and the significance of the time factor in human tolerance to impact. Protective and preventative measures are discussed.

207

Ruff, S., "Human Resistance to Certain Types of Uneven Acceleration. (Ueber die Beschleunigungsfestigkeit des Menschen... Beschleunigungen)," ASTIA ATI 47632, 1942.

ABSTRACT: Studies were made by the German Aeronautical Research Institute on human resistance to certain types of shock accelerations. Results of experiments are discussed pertaining to the distribution of forces acting upon certain parts of the human body in airplane crash landings, parachute shocks and in the ejection of catapult type seats in modern aircraft. It was concluded that in airplane crash landings the body can tolerate force up to 26 g, with the necessary precautions, without injury. Experiments have proven that a 2000 kg shock can be absorbed without injury in parachute opening and 20 g can be endured with the ejection catapult seat.

208

Ruff, S., "Medical Problems Concerning Parachute Jumps from High Altitudes and at High Velocities," The Ejection Seat for Emergency Escape from High-Speed Aircraft, Appendix 5, ASTIA ATI 7245, 1945.

ABSTRACT: With the steadily increasing performance of our aircraft a series of medical problems has arisen which are related to existing rescue devices and to others still to be developed. This report discusses briefly that phase of aviation medical knowledge and investigation which deals with the above questions - that is to say, with parachute jumps from present-day and future aircraft. The medical problems which arise in bailing out from modern aircraft are to be attributed to flight at increasing altitudes and at ever increasing velocities.

209

Ruff, S., "Protection against Possible Injuries Caused by Airplane Crashes (Unfallerfahrungen)," Part 5 of 10 parts, ASTIA ATI 60742, March 1937.

ABSTRACT: Protective measures against possible injuries to flying personnel by airplane crashes were investigated. Statistics show an overwhelming number of head injuries in airplane crashes. The causes of the injuries were investigated, and suggestions for the protection of personnel are presented. It is suggested that in addition to the crash-helmet, the pilot should be fastened to the seat by several belts (one belt around the abdomen being insufficient). The back strap should be tight enough and fastened in such a manner as to prevent a forward surge of the body. Suggestions for cockpit-seat improvements are made.

210

Safety and Survival Equipment, Navaer 00-8-T-52, 1959.

ABSTRACT: This manual is prepared for the survival officer and the Flight Surgeon as a training guide with general but comprehensive coverage of the various items of safety and survival equipment. The write-ups for most items list some technical features.
The described equipments are:
1. Oxygen equipment
2. Parachutes
3. Safety belts and harnesses
4. Ejection seat
5. Flight clothing
6. Emergency protective clothing

211

Santi, G. P., "Acceleration Problems in Ejection-Seat Design," Supplement to Shock and Vibration Bulletin, No. 22, p40-47, Office of the Secretary of Defense, Research and Development, Washington, D. C. July 1955.

ABSTRACT: Tests conducted to measure forces operating in the D-ring firing system of downward-ejection seats and in the ejection of seats through plexiglas canopies are described. A loaded spring shock absorber was developed to reduce forces on the D-ring after dummy ejection tests during flight at speeds of 225 to 425 knots revealed the operation of intolerable forces at higher speeds. Successful live ejections were conducted with the new device to a maximum air speed of 423 knots. Force measurements made during the ejection of a dummy through a laminated plexiglas canopy indicate a maximum vertical impact force of 9000 pounds and an apparent breakthrough force of 2600 pounds.

212

Santos, F. R., "Medical Problems of Emergency Escape from High Speed Aircraft (Problemas Medicos da Saida de Emergencia Avioes de Grande Velocidade)," Imprensa Medica (Rio de Janeiro), 27:81-92, February 1951.

213

Saul, E. V., etal, Human Engineering Bibliography 1956-1957, Contract NONR 494(13), ONR Rept. ACR 32, Naval Engineering Psychology Branch, Office of Naval Research, Washington, D. C., October 1958.

ABSTRACT: Personnel responsible for the human factors considerations in the design and development of equipment have a major need for rapid and easy access to the literature pertinent to their work. This bibliography is one of a planned series of annual bibliographies of literature pertinent to human engineering designed to meet this need. There are five main parts: 1) a topical outline that defines over 300 topic headings, 2) an index that relates the bibliographic entries with the topic headings, 3) an alphabetic index of search terms, 4) an annotated bibliography, and 5) an index of authors.

214.

Savely, H. E., "Human Problems in Escape from High Speed Aircraft," Air University Quarterly Review, 5:65-67, Spring 1952.

215

"Servicing Memorandum (STS-29-3) and Test Report (UM-29-9. 04:RI) for Saab Ejection Seat," Library Translation No. 370, Royal Aircraft Establishment, Farnborough, England, ASTIA ATI 113968 or AD 26614, 1951.

ABSTRACT: A number of new points of view have emerged concerning the production of ejection seats. Among others, an ejection velocity of about 18 mps is desired together with retention of the earlier max. acceleration and rate of rise of acceleration. This performance agrees with the possibility of safe ejection at max. speed under the influence of the mass inertia forces operating in the line of ejection. Another more recent desirable feature is that the acceleration is balanced so that a high finishing acceleration is obtained, by means of which a better balance is attained by means of inertia forces and aerodynamic forces. The higher limit of flying speed, where there is a risk of breaking up the seat at the end of an ejection, may then be further increased. Concerning the calculations for free trajectory and safe speed see S.A.A.B. report KFB-0-110 and UM-29-9-12. The objectives already mentioned have been allowed for in the test equipment on which these series of tests are being continued. By means of a higher testing railway rig at S. A. A. B. it is now possible to test with Vo values up to 21 m. p. s. The accelerations can, to a certain extent, be influenced by the use of different cordite and throttling than has been so far used, although the dimensions of the pressure chambers which may now be regarded as finalised, can limit the possibilities; even so due allowance must be made for the density of the charge, max. pressure, and dimensions of the cordite etc.

216

Schneider, J., "Protective Measures for the Prevention of Injuries - Especially Spinal Fractures - In Aircraft on Skids," German Aviation Medicine, World War II, Chapter VI-E, Vol. I, pp. 612-616, U.S. Government Printing Office, Washington, D. C., 1950.

ABSTRACT: A brief mathematical exposition of the determination of forces involved in aircraft accidents is presented. Protective measures for pilots of skid equipped gliders, to reduce ankle and spinal fractures, are described.

217

Schrenk, O., and R. Irrgang, "Studies on the Catapult Seat," The Ejection Seat for Emergency Escape from High-Speed Aircraft, Appendix 3, ASTIA ATI 7245, 1945.

ABSTRACT: The accelerations which can be tolerated by human beings depend very greatly upon direction and are also significantly greater when the time of

action is short than they are when it is long. These physiological conditions must be taken into account in the design of a catapult seat. During the process of ejection of a pilot successive accelerations acting in different directions come into effect. It is shown by experiments with models and by calculations at the Ernst Heinkel aircraft factory that the accelerations which occur are physiologically tolerable although they sometimes approach the limit of tolerance. The vertical accelerations required in the actual ejection are especially favorable when designed for the clearance of a double tail (7 g, compared with 18 g in the case of a central vertical stabilizer). The backward acceleration caused by air movement is about 24 g in the most unfavorable case considered here (v = 900 km./hr.; see Figure 16). This acceleration can just be tolerated in the vertical position; it diminishes very rapidly. Steps must be taken to insure that after the ejection the pilot is not turned head over heels and thus brought into the physiologically dangerous horizontal position in which the acceleration will act in the direction of the feet. It is best to arrange for a gentle backwards rotation under all conditions. The results of the investigation are established by means of various model experiments and calculations.

218

Shannon, R. H., USAF Seat Ejections, 1 January 1959-31 December 1959, Report No. M-10-60, Directorate of Flight Safety Research, Norton Air Force Base, California, ASTIA AD 242728, July 1960.

ABSTRACT: The data contained in this report were compiled from questionnaires completed by crewmembers who used the ejection seat as a means of escape during inflight emergencies and from aircraft accident reports submitted on accidents involving ejection during 1959. Intentional or inadvertent ejections subsequent to ground impact are not included.

It is the intent of this report to advise research and development agencies of current problem areas and to provide operating personnel with an up-to-date analysis of USAF ejection experience.

These data provide the background information for extensive aircrew indoctrination concerning pre-ejection, ejection, and post-ejection conditions.

219

Shapland, D. J., "Dynamic Models for Determining Human Tolerance to Abrupt Accelerations," presented at the 33rd Annual Meeting of the Aerospace Medical Association, Atlantic City, N. J., 9-12 April 1962.

ABSTRACT: Spring-mass systems analogous to the human body subjected to short

duration accelerations are proposed and criteria suggested that can be applied to the response of these systems to indicate degrees of tolerance of the human body. The basic mathematics governing the motion of linear and non-linear, damped single-degree-of-freedom models is described and the equations of two- and three-degree-of-freedom models developed. Comparison of the solutions with available experimental data enables the dynamic characteristics of the models to be established for the spinal and transverse directions. Analytical solutions are possible for simple acceleration time inputs and complex inputs can be studied using digital computer techniques. A special purpose electronic analog computer that has been developed for rapid evaluation of complex inputs is also described. The dynamic models can be used to predict human tolerance to arbitrary inputs and also to ascertain the influences of seat cushions and restraint system effects. Examples of the use of the models are given and their advantages and limitation discussed.

220

Shapland, D. J., "The Dynamic Model - An Engineering Approach to the Problem of Tolerance to Abrupt Accelerations," presented at the Symposium on Impact Acceleration Stress, Brooks Air Force Base, San Antonio, Texas, 27-29 November 1961.

ABSTRACT: The tolerance of the human body to short duration accelerations can be analyzed with the aid of analagous dynamic models, consisting of spring-mass systems. The basic principles of this technique are discussed in an attempt to clarify this method of investigating the problem. The basic models used are explained, and the methods of application described.

221

Shaw, R. S., "Human Tolerance to Negative Acceleration of Short Duration," J. Aviation Med., 19(1):39-44, February 1948.

ABSTRACT: Experiments have been conducted to determine the tolerance of humans to forces like those which would be experienced in escape from aircraft by downward seat ejection. It has been found that seated human subjects can tolerate considerably more than 3 negative g for periods of time under 0.3 seconds.

222

Shaw, R. S., "Ruptured Intevertebral Disc from Positive Acceleration," J. Aviation Med., 19(4):276-278, August 1948.

ABSTRACT: 1. Back injury from positive acceleration is reviewed.

2. A case of proven and a case of probable herinated nucleus pulposus resulting from a dive "pull-out" are reported.
3. A flexed back predisposes an individual to this injury during positive acceleration and should be avoided.

223

Sinnamon, E. G. and W. S. Wray, Bibliography of Aviation Medical Laboratory Publications, 1950-1960, NADC-MA-6211, U. S. Naval Air Development Center, Johnsville, Pa., 27 September 1962.

ABSTRACT: A bibliography with abstracts and indices is presented which covers all of the published work of the Aviation Medical Acceleration Laboratory during its first decade, 1950-1960. The primary facility at this laboratory is the 50-foot radius human centrifuge with its gimbal-mounted gondola. This device is capable of producing acceleration levels up to 40 G and with computer control can realistically simulate flight profiles of air and space vehicles. The subject matter covered by the publications includes aviation and space medicine, the effects of acceleration on the animal and human organism, human performance under acceleration stress, dynamic simulation of aircraft and space vehicles, biochemistry, physiology, psychology, and engineering. Included are formal reports, progress reports, and articles which appeared in the open literature. The material is coded and grouped under subject headings and indexed by author, title and report number or journal citation. ASTIA numbers are given for all reports available under that system.

224

Smiley, J. R., RCAF Ejection Experience Decade 1952-1961, Technical Memo. 64-TM-1, RCAF, Institute of Aviation Medicine, Toronto 12, Ontario, Canada, 1964.

ABSTRACT: The first RCAF ejection was a successful escape from an F86 aircraft, 9 April 1952. In the ensuing decade 218 ejections took place out of which 165 aircrew survived. Each of the 165 has made a report on his experience, procedures and equipment. Where possible these data have been summarized or coded for analysis. This report shows the general background giving rise to ejections and the trend of survival rates by years. A review is then made of the circumstances surrounding fatal and successful ejections together with relationship between altitude, attitude and airspeed. The descent phase is examined in terms of retention of equipment, control and problems of landing. A summary of survival and rescue experience is then presented together with a summary of water landing. Of major interest is the study of injuries by type and site according to aircraft, phase of escape, preparation for ejection, control of descent and landing conditions. It has been found that the Martin-Baker

seat does not give rise to so high a spinal fracture rate relative to other ejection systems as commonly thought.

225

Snyder, R. G., A Case of Survival of Extreme Vertical Impact in Seated Position, CARI Report 62-19, Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma, October 1962.

ABSTRACT: Physical, biophysical, and medical data are presented concerning the case of a 20 year old male in excellent physical condition who jumped from the Golden Gate Bridge in San Francisco, surviving for ten days a free-fall deceleration in the seated position (buttocks to head) of a calculated 4128 g for .0023 seconds. Specific trauma resulting from this impact indicates that this may closely approach the extreme human survival tolerance(s) to impact in this position, and that, while distribution of forces through support of the upper torso may greatly minimize injury to the skeletal system, protection of internal organs will present a much more difficult problem.

226

Snyder, R. G., "A New Approach to the Problem of Increasing Human Tolerance to High Deceleration Forces," Journal of the Arizona Academy of Science, 1(2):68-71, 1959.

ABSTRACT: Preliminary design and theory of a full back brace restraint system intended for wear under flight clothing by pilots of high performance aircraft is briefly described. It is hypothesized that such a protective device might not only decrease physical fatigue on long flights, but due to its individual support characteristics might offer a method of substantially increasing human tolerance to abrupt multi-directional deceleration forces. Such a system might have an immediate usefulness in reduction of the present high incidence of vertebral fractures incurred by pilots of high performance aircraft, and might be utilized by personnel of space vehicles.

227

Snyder, R. G., "Bracing Man for Space Flight," presented before the American Anthropological Association and Sociedad Mexicana de Antropologia, Mexico City, Mexico, December 1959.

ABSTRACT: The author of this paper discusses a frequently encountered aspect of abrupt deceleration which occurs in the field of aviation—that of the

vertebral injury. Vertebral fractures are of particular concern due to the increasing incidence of this type of injury resulting from high impact situations. A major explanation for the increasing incidence of vertebral injuries appears to be due to the increase in the vertical component of deceleration force diagrams. Present restraint systems do not give adequate support because they are basically designed for lineal deceleration protection only. Recognition of this point is observed in the recent modification of the shoulder harness inertial reel locking device in fighter type aircraft. The proposed bracing restraint is designed to keep the back in optimal position for high deceleration loads. Use of a bracing restraint would tend to keep the back in optimal position for such loads. In regard to comfort it is believed that if this support were properly fitted and snugged, it would provide the pilot with support which he does not have at present. The most important consideration in such a system is the degree of additional protection which could be obtained. In instances of abrupt deceleration while wearing such a device, the force normally borne by the lumbar area of the vertebral column would be partially absorbed by the bracing system.

228

Snyder, R. G., Human Tolerance Limits in Water Impact, Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma, 1965.

ABSTRACT: The wide but overlapping range presented between human levels of clinical impact trauma, as measured in the laboratory on volunteer subjects, and the extreme limits of survival which may occur in free-fall, have long presented a scientific enigma. This study has been an attempt to identify and evaluate factors critical to protection and survival in human water impact. Theoretical mathematical basis for impact loadings on the body was tested in experimental impact tests of human voluntary subjects, anthropometric, and cadaver materials. Sixty cases of free-falls survived by individuals impacting water environments at over 50 ft./sec. during the past three years were intensively investigated and analyzed. In addition, autopsy data in fatal falls occurring under similar environmental conditions during this time was compared; however, it was found that fatal cases often presented a problem as to whether death was caused by drowning, and if so, whether the impact trauma could have been survivable. The most survivable body orientation, by a factor of 5-7 times, was found to be a (+Gz) feet-first deceleration in which critical velocity for human survival was about 100 ft/sec. Patterns of injury and relationships of factors found to influence human survival tolerances are presented and compared with impact trauma on non-water surfaces.

229

Snyder, R. G., "Human Tolerances to Extreme Impact in Free-Fall," Aerospace Med., 34(8):695-709, August 1963.

230

Stapp, J. P., "Effects of Mechanical Force on Living Tissues, I. Abrupt Deceleration and Windblast," J. Aviation Med., 26:268-288, August 1955.

ABSTRACT: Human experiments on a rocket propelled linear decelerator sled capable of higher than 25 g decelerations for longer than one second durations have determined parameters for limits of reversible incapacitation of volunteer human subjects. These limits of human tolerance relate to decelerations experienced during escape from high performance aircraft by means of an ejection seat during wind drag deceleration at high ram pressures encountered in supersonic flight.

A simultaneous study of windblast effect due to impingement of ram pressure against the exposed body of the subject indicates that 7.7 pounds per square inch, or 1,108 pounds per square foot of ram wind pressure has no significant effect on a subject whose head is shielded by a complete enclosure, and whose head and extremities are restrained against flailing. Indications are that decelerations exceeding one second for higher than 25 g can be a limiting factor requiring modification of the deceleration reaction of seat and occupant to supersonic ram pressures. On the basis of these and previously reported human experiments it is postulated that a refractory period of one-tenth second with respect to hydraulic displacement effects within the body determines very high impact tolerance.

In this range tissues fail in the same manner as inert materials by exceeding physical characteristics of tensile, compression, or shear strength. Beyond this range, tolerance to mechanical forces is determined by reaction to hydraulic displacement of fluids. Hydraulic pressure rupture of blood vessels and pressure damage to cell membranes set the limit to tolerance. Hydraulic pressure values, on the other hand, tolerable to living tissues but lasting more than three seconds, can produce a secondary hypoxia due to circulatory stasis. Such hypoxia in nervous tissue can reach a duration limit for uninjured survival. These responses represent a continuous spectrum of reaction to mechanical force related to rate of application, magnitude of force, duration of application, and its direction.

231

Stapp, J. P. and Neely, S. E., High Speed and Thunderstorm Effects on USAF Ejections, 1949-1960, Publication No. 20-61, Deputy Inspector for Safety, Norton Air Force Base, California, ASTIA AD 285132, April 1961.

ABSTRACT: Utilizing USAF aircraft accident reports, those accidents involving high speed ejections (both supersonic and over 500 knots) and thunderstorm

ejections are analyzed. The influence of high speed and thunderstorm conditions on ejection are evaluated. Five accidents are briefed including a recent multi-jet accident in which both factors were present. Conclusions are drawn concerning the significance of the factors studied.

232

Stapp, J. P., "Human Tolerance Factors in Supersonic Escape," J. Aviation Med., 28(1):77-82, February 1957.

ABSTRACT: Measures must be taken to permit escape from aircraft on the ground or at low flight levels, and to avoid inadvertent ejections through the canopy. The effects of wind drag deceleration, tumbling and spinning, and wind blast, encountered in high-altitude and high-speed ejections, must be kept within human tolerance limits. These effects may be minimized in a "rideable" ejection seat. The rideable seat would lend itself to low-level escape more readily than would an ejection capsule, and, in the interest of economy and overall aircraft efficiency, it may be the best arrangement for a long time to come.

233

Stapp, J. P., "Human Tolerance to Deceleration," American J. Surg., 93(4):734-740, April 1957.

ABSTRACT: In order to accomplish precisely controlled exposures of living organisms to predetermined configurations of mechanical force with reasonable safety, the chosen instrument has evolved as a rocket or catapult-powered sled, slipper mounted on rails, carrying the subject, recording and transmitting instrumentation and braking devices, which can be accelerated to the required velocity and then decelerated according to plan. It can be concluded from the results that the structural strength of the human body, its energy absorbing characteristics with respect to brief applications of high dynamic loads, its tolerance to abrupt wind blast of nearly explosive violence facilitate salvaging the victims of high speed transportation accidents. The application of this knowledge can lead to a great saving of lives and prevention of disabilities.

234

Stapp, J. P., "Jolt Effects of Impact on Man," presented at Symposium on Impact Acceleration Stress, Brooks Air Force Base, Texas, 27-29, November 1961.

ABSTRACT: The paper contains reports on several impact, acceleration, and deceleration experiments.

235

Stapp, J. P., "Problems of Human Engineering in Regard to Sudden Decelerative Forces on Man," *Milit. Surg.*, 103(2):99-102, August 1948.

ABSTRACT: The article points out some of the problems, methods, and viewpoints of human engineering applied to the field of linear decelerative forces of rapid onset, brief duration, and high magnitude and their effect on the living human body.

236

Stapp, J. P., and H. P. Nielsen, *Proposed Tests for Escape from Very High Velocity Aircraft*, Holloman Air Development Center, Holloman Air Force Base, New Mexico, ASTIA AD 26 626, 1953.

ABSTRACT: The hazards faced by crew members when they escape from high-speed aircraft at high altitudes are described. At 15,000 ft. problems arise from the low temperature, low atmospheric pressure, tumbling and spinning, wind blast, and deceleration. The literature concerning the effect of such factors on human physiology is reviewed. In the study of the effects of deceleration on the human body, a highspeed sled, track, and water braking system are considered.

237

Stech, E. L., *A Review of Restraint System Test Methods*, Paper No. 63-WA-279, American Society of Mechanical Engineers, New York, N.Y., 1963.

ABSTRACT: This report reviews the available methods of restraint testing including the conditions of testing, use of live human subjects, use of cadavers and animals and the use of anthropometric dummies. The methods and philosophy presented here are applicable to other Biomedical Engineering areas of testing, not just to restraint system testing alone.

238

Stech, E. L., *The Effect of Age on Vertebral Breaking Strength, Spinal Frequency, and Tolerance to Acceleration in Human Beings*, Technical Report 122-101, Contract No. AF 33(657)-9514, Aerospace Medical Laboratory, Bioastronautics Division, Wright-Patterson Air Force Base, Ohio, January 1963.

ABSTRACT: Age results in decreased vertebral compressive strength, in terms of either endplate fracture or proportional limit definitions of strength. Data obtained by Perey in Sweden shows that the two types of strength measurements are consistent when plotted against age. Quantitative estimates of the relationship between age and strength are provided by an analysis of the experimental strength data.

Somewhat surprising is the finding that the compressive stiffness of vertebral bodies decreases with age. This result is obtained by statistical analysis of some of Perey's data, and comparison is made between the predicted shift in natural frequency of the spinal column with advancing age and actual changes observed with live human beings on shake tables. The predictions based on cadaver data are shown to be within 2 per cent of the empirically measured frequencies of live subjects.

The combination of changes in strength and stiffness is shown to affect the predicted tolerance to impact acceleration forces, and the projected magnitude of the reduction in tolerance is presented graphically.

239

Stech, E. L., <u>The Use of a Subjective Acceleration Severity Index in Restraint System Tests</u>, Technical Report 122-102, Aerospace Medical Laboratory, Bioastronautics Division, Wright-Patterson Air Force Base, Ohio, January 1963.

ABSTRACT: A review was made of data collected and made available by the Civil Aeromedical Research Institute on live human subject drop tests. During the data review, it was noted that subject comments might be useful as a measurement of acceleration severity. The subject reports were quantified through the use of a rating scale and then averaged for each drop height and cushioning condition. When plotted against the impulsive velocity change involved, the averaged subjective index illustrated results which would be predicted by support system dynamic models. Therefore, the index scale can be considered valid. The scale also showed a reasonably good accuracy in terms of differentiating between various impact-cushion conditions. In addition, an average subjective endpoint at 11.2 fps for pure impact was obtained from the data which also indicated that the head becomes the controlling factor in tolerance to short rise time acceleration pulses.

240

Stech, E. L., <u>The Variability of Human Response to Acceleration in the Spinal Direction</u>, Technical Report 122-109, Contract No. AF 33(657)-9514, Aerospace Medical Laboratory, Bioastronautics Division, Wright-Patterson Air Force Base, Ohio, May 1963.

ABSTRACT: The variability of vertebral breaking strength, as evidenced by cadaver test data, is examined and estimates of the probability of damage distributions are made. Three types of vertebral damage are studied: endplate fracture,

vertebral body proportional limit strength, and vertebral body irreversible compression fracture. It is shown that the probability of damage curves can be used to generate operational probability of injury curves if the user age distribution and input acceleration distribution are known. A sample injury rate probability study is presented.

241

Stewart, W. K., Ejection of Pilots from Aircraft. A Review of the Applied Physiology, Report No. 671, Flying Personnel Research Committee, Great Britian, ASTIA AD 222472, September 1946.

ABSTRACT: For seat ejection two general stages are envisaged. Firstly, ejection from the aircraft, which in itself is a great advance but implies a conscious pilot for preservation of life; secondly, development of ejection with ancillary automatic mechanism to ensure that an unconscious pilot will avoid severe injury. Cabin jettisoning is of primary importance for very high altitudes or very high speed aircraft and should be thoroughly investigated. If it proves acceptable physiologically, the final provisions for escape should include both jettisoning and ejection, but where this proves impossible in any given case, it should be the function of some central authority or committee to state which system has to be installed.

242

Stewart, W. K., and H. L. Roxburgh, German Occupation Disarmament: Aviation Medical Aspects in Schleswig-Holstein, Report No. 627, Appendix 14, Flying Personnel Research Committee, Great Britian, May 1945.

ABSTRACT: Results of the interrogation of German personnel.

In response to questions about the ejection seat, the Squadron Commander gave the following information:

Experiments were first carried out on a ground test rig at the Heinkel aircraft works. This rig, essentially constructed from inclined rails, would appear to have been similar to the Martin-Baker test rig, and to have a vertical height of at least 10 m.

A compressed air system of propulsion was first investigated and abandoned in favour of an explosive charge.

Accelerations of 4-6 g were first investigated and gradually increased to 14 g which was the acceleration necessary for clearance from the Me. 162.

The duration of the acceleration was not known but the distance of propulsion at ground level was stated to be 10 m. and it is considered that these figures are

reasonably consistent with present R.A.F. knowledge. At this acceleration, it was necessary to hold the head back and to place the feet on supports. The Squadron Commander did not himself notice any marked difference between the acceleration values of 6 and 14 g.

The highest of g reached in the tests was 26; a few cases of back injury occurred but these had not been observed by the officer.

He stated that the apparatus had actually been used in emergencies on two to three occasions and he thought that the maximum air speed had been 800 Km/hr. (500 mph). No difficulty had been commented on, either in separating from the seat or in autorotation after ejection. He could not state whether any masks had been dislodged in the air blast.

243

Swearingen, J. J. et al, Kinematic Behavior of the Human Body During Deceleration, Report No. 62-13, Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Okla., ASTIA AD 283938, June 1962.

ABSTRACT: The geometry of motion of the head, trunk and appendages was established for one hundred male subjects restrained by a safety belt during forward and side dynamic loadings. Lethal structures of present aircraft seating and cockpit arrangements are revealed by correlating crash injuries with these kinematic data. In addition an analysis of the forces created by body kinematics during forward deceleration sheds new light on seat anchorage problems.

244

Swearingen, J. J., and R. G. Snyder, "Human Tolerance to Vertical Impact," presented at the Symposium on Biomechanics of Body Restraint and Head Protection, Naval Air Material Center, Philadelphia, Pa., 14-15 June 1961.

ABSTRACT: The results of several studies concerned with the voluntary physiological tolerance limits and transmission of impact forces parallel to the body's longitudinal axis (caudal-cranial) are presented. Over 500 tests of 13 male subjects were conducted utilizing an instrumented drop test apparatus. Impact forces at the foot and seat level and attenuation at shoulder level was measured for each subject. Results of the seated impacts showed that subjects seated on a rigid chair seat reached voluntary tolerance (complaints of severe pains in chest, head, abdomen, and lumbar spinal areas) when the shoulder accelerometer reached 10-12 G at over 600 G/sec. with mean initial impact loads of 95 G (.0075 sec, 19,000 g/sec jolt). Various materials and methods including Styrofoam, polyvinyl chloride, undrawn nylon, horsehair and rubber, hydraulic bleed pistons, and Stafoam were studied in an attempt to increase the deceleration time and subjects tolerance. Of these, Stafoam indicated most promise as a significant damping agent. Stand-

ing impact tolerance was studied with knees locked stiffly and with knees flexed. Attempts to determine static leg loading through double exposure X-rays was essentially negative. Strength of the legs at various knee angles in both static and dynamic tests, and human tolerance to impact in the squatting position were also investigated. Brief discussion of more recent vertical deceleration research activities at CARI are noted.

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Swearingen, J. J. et al, Protection of Shipboard Personnel against the Effects of Severe Short-Lived Upward Forces Resulting from Underwater Explosions, Navy Contract NAonr 104-51, Civil Aeromedical Research Institute, Protection and Survival Branch, Oklahoma City, Okla., January 1960.

ABSTRACT: Relative strength of the legs at various knee angles was determined in the standing position by three different test procedures. Man's weakest knee angle was found to be 60°.

X-ray studies of the legs and feet during vertical loading failed to reveal any bending of the femur or tibia or compression of cartilages in the knee or ankle. There was a slight lateral bending of the fibula and the tarsal and metatarsal bones were displaced downward.

Human voluntary tolerances to vertical impact were determined while (1) standing with knees locked, (2) standing with knees bending, (3) squatting, and (4) seated in a rigid chair. In addition, various energy-dissipating materials and devices were evaluated for protection against vertical impact. These tolerances and evaluations are summarized in Table I.

246

Synopsis of the Aero Medical Aspects of Jet Propelled Aircraft, Aero Medical Laboratory, Air Material Command, ASTIA ATI 56134, January 1949.

ABSTRACT: Brief reviews of recent developments and current practices are presented on the following subjects: requirements and equipment, decompression sickness, cabin pressurization, explosive decompression, long term positive and negative acceleration, pilot's pneumatic suit for positive acceleration, cockpit design and temperatures, flight instruments, psychological limitations, sound problems, the ejection seat, protective helmets, wind-blast protection, and vision. Future research will be concerned with protection under emergency conditions in a vacuum, etc.

247

"The Ejectable Seat of the Martin-Baker MK4," Aviation Magazine, (238):24, 25, 1 November 1957.

ABSTRACT: A detailed description of the ejection seat of the Martin-Baker MK4 type is given in this article. The discharge mechanism and the ignition is described. Furthermore, the parachute and the opening of the head parachute are discussed. Several ties are fastened to the chair to prevent the legs from moving around during firing. The ignition is 83 ft/sec, the maximum acceleration 20 g. The chair weighs 40 kilos.

248

The Martin-Baker Automatic Ejector Seat - Mark 3, Martin-Baker Aircraft Co., Ltd., England, ASTIA ATI 88684.

ABSTRACT: The design of the Martin-Baker automatic ejector seat is described which enables pilots and aircrew personnel to escape from high-speed aircraft at all altitudes. It is effective at any speed and under any G accelerations that may occur whatever the altitude of the aircraft. By the simple movement of a hand lever, the airman has his parachute available for normal rip-cord operation either without ejection with the seat or at any time after ejection has taken place. The seat is ejected from the aircraft by means of a cartridge operated gun and slides during ejection on four rollers in a guide rail. The ejection gun is fired by the withdrawal of a flexible screen, which covers and protects the occupant's face against the effects of the air stream. On ejection, the seat leaves the aircraft at 60 fps.

249

Thompson, A. B., "A Proposed New Concept for Estimating the Limit of Human Tolerance to Impact Acceleration," Aerospace Med., 33(11): 1349-1355, November 1962.

ABSTRACT: Mathematical techniques are being developed for determining human whole body response to various impact accelerations, but no satisfactory method is available for defining the human response tolerance limit to impact loads resulting from abrupt decelerations. Limits set by total G vs. time, rate of onset, and velocity change are ill-defined and variable. A concept is proposed whereby limits are set by the force exerted per unit area on the body by the restraint or support system at maximum deceleration. Correlation is made between blast tolerance, sled test tolerance, and automobile accident and fall impact survivals which indicates that 28 to 32 pounds per square inch is the onset level for shock and 45 to 55 pounds per square inch is the level for 50 per cent mortality for transverse accelerations of less than 0.07 second duration. In this concept G, rate of onset, and onset time are all dependent variables while impact force per unit area, delta velocity change and impact pulse time define the tolerance envelope.

250

USAF Seat Ejections, 1 January 1960 - 31 December 1960, Publication No. 16-61, Deputy Inspector General for Safety, Norton Air Force Base, California, ASTIA AD 285134, 1961.

ABSTRACT: Data were compiled from questionnaires completed by crew members who used the ejection seat as a means of escape during inflight emergencies and from aircraft accident reports submitted on accidents involving ejection during 1 January - 31 December 1960. Intentional or inadvertent ejections subsequent to ground impact are not included. An evaluation of the data was made to advise research and development agencies of current problems and to provide operating personnel with an up-to-date analysis of USAF ejection experience that may be used as a guideline for extensive aircrew indoctrination concerning pre-ejection, ejection and post-ejection conditions.

251

Valentine, G., Dynamic Analysis - Emergency Escape Systems, Document No. 451, Contract No. AF 33(600)-32054, Stanley Aviation Corp., Denver, Colorado, ASTIA AD 115879, 13 July 1956.

ABSTRACT: This report presents an appraisal of twelve configurations of emergency escape devices. They are: (1) Upward seat, forward facing; (2) Upward seat, forward facing with added mass; (3) Downward seat, forward facing; (4) Downward seat, forward facing with added mass; (5) Seat-capsule, forward facing; (6) Seat-capsule, forward facing with added mass; (7) Upward seat aft facing; (8) Upward seat aft facing with added mass; (9) Downward seat aft facing; (10) Downward seat aft facing with added mass; (11) Seat capsule, aft facing; (12) Seat capsule, aft facing with added mass. The following characteristics of the more promising of these configurations were determined for ejection at 650 knots EAS at sea level and 44000 feet altitude; (1) Trajectory to tail. (2) Spinal and cross-body accelerations vs. time. (3) Pitching acceleration, velocity and altitude vs. time. Also determined were thruster requirements for upward ejection at maximum q and minimum airspeed and low altitude escape limitations for critical configurations.

252

Violette, F., "French Observations and Researches Concerning Impact and Crash," Impact Acceleration Stress, pp 35-38, Publication 977, National Academy of Sciences, National Research Council, Washington, D. C. 1962.

ABSTRACT: Observations and research results of the French Air Force Medical Corps on impact and crash include the following: (1) For wounded patients that are carried with feet forward on longitudinally set stretchers, two straps are sufficient — one on the base of the thorax, the other on the middle of the thighs. These straps, usually moderately tightened, must be sufficiently tightened in case of crash to prevent any slipping of the wounded on the stretcher. The restraint may be comfortized: (a) with stoppers placed on the arms of the stretchers, and (b) by broadening the straps (three inches or 7.5 cm). A release-pin system is recommended for quick strap release. (2) The telescopic ejection seat is superior to the ejection seats with solid axis guns. Also, the breaking-joint of the spine was about the seventh thoracic vertebra. In addition, a helmet chinstrap in high-speed ejection is both useless and dangerous. (3) In the emergency ditching of a helicopter, the impact shock on the cabin floor was not felt by the standing crew members; nevertheless, the pilot and co-pilot both received spinal fractures although well strapped. In such accidents the impact deceleration may be transmitted without softening from the floor to the seat and to the strapped subject.

253

Virgin, W. J., "Experimental Investigations into the Physical Properties of the Intervertebral Disc," J. Bone Joint Surg., 33B(4):607-611, November 1951.

ABSTRACT: In four experiments whole sections of the spine were tested to observe the effects upon series of discs. The findings were essentially the same as for single discs. In each specimen the deflection was the sum of the deflections of the contained discs. In other respects also the behaviour of multiple segments of spine was similar to that of single discs. Angular incisions into the annulus of one of the discs in the segment caused interference with recovery, whereas simple linear incisions had no effect.

1. The intervertebral disc is an organic viscous elastic structure capable of maintaining very great loads without disintegration.
2. Recovery of the disc after deformation depends upon: a) the imbibition of tissue fluid by the disc, b) the removal of the deforming force. Complete recovery is modified by the duration of the force.
3. Factors that interfere with the elasticity of the disc are: extreme youth

(immaturity of the disc), chronic wasting diseases (general nutritional disturbance), and local pathological changes in the bodies of the vertebrae which interrupt or damage its blood supply. The intervertebral disc reaches its greatest state of efficiency in adult lift—that is, when the nucleus pulposus has disappeared as an entity. The function of the disc appears not to depend upon the presence of the nucleus: rather does the presence of the nucleus indicate immaturity of the disc.

4. The highly resilient elastic nature of the vertebral column is provided by the intervertebral discs, which constitute one-third of the whole length of the column.

5. The imbibition of fluid requires further investigation. It appears that from lacunae in the adjacent bodies finger-like pockets dip into the discs and that fluid passes through the lining membrane of these pockets.

254

VonGierke, H. E., "Biodynamic Response of the Human Body," Applied Mechanics Reviews, 17(12):951-958, December 1964.

ABSTRACT: The word biodynamics has evolved as the unifying term describing the dynamic mechanical properties of living systems and the effects of various mechanical force environments on these systems. The breakdown of the force environments into sustained acceleration, hypodynamics, impact, vibration, blast, acoustics, etc., has its justification more in historical reasons, simulation techniques and practical requirements than in a basic systematic approach to the mechanisms involved. Notwithstanding obvious differences with respect to problems, techniques used and some apparent differences in biological reactions to the various forms of mechanical energy, this paper reports and reviews results of recent studies emphasizing the common background and the physical phenomena applying to the whole field. The status and value of mathematical models for studying the body's response to pressure (infrasonic noise, blast) as well as force changes (vibration, impact) are presented and the practical application of such models for explaining physiological and pathological findings, for predicting the body's response to force environments not yet experienced, for protection engineering and biomedical problems in general is discussed.

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VonGierke, H. E., et al, "Physics of Vibrations in Living Tissues," J. Applied Physiology, Vol. 4, No. 12, 1952.

256

VonGierke, H. E. and R. R. Coermann, "The Biodynamics of Human Response to Vibration and Impact," Industrial Med. and Surg., 32(1):30-32, January 1963.

ABSTRACT: In summary, it can be concluded that there is a definite relationship between vibration and impact tolerance and that the mechanical models derived from steady state vibration studies are very helpful for the interpretation and prediction of impact tolerance data. However, further refinement of these models and study of other load directions are necessary. Knowledge of the dynamic properties of the human body, of the body of various animals and of dummies are of particular value for drawing any valid conclusions from animal or dummy experiments as to their meaning with respect to human subjects.

Finally, theoretical analysis of the response of the complex human system to impact loads shows clearly that a complete description of the force time function of the impact load is necessary to define response or tolerance uniquely. Only in very limited impact duration ranges can single parameters like peak acceleration, impulse or rate of onset be considered as quantity of primary importance for the response.

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Waecker, N. J., Description of Rocket Catapults XM8, XM9, XM10, XM12, Technical Memo. No. M59-28-1, Project No. TS1-15, Frankford Arsenal, Philadelphia, Pa., ASTIA AD 217240, May 1959.

ABSTRACT: The physical and performance characteristics of 3 rocket-assist catapults are presented. Each catapult consists basically of two assemblies, an outer tube assembly, which is mounted to an airframe structure, and a telescoping inside tube assembly, which contains the rocket motor. This inside tube assembly is connected to an ejection seat. During ejection, a booster propellant, located in the inside tube, is ignited and the tube telescopes out of the launcher, carrying the ejection seat and man. The stroke of the telescoping action varies on the different catapults from 34 to 40 inches. Near the end of the stroke, the rocket motor solid propellant is ignited, supplying the necessary thrust for carrying the ejection seat with man clear of the aircraft and into free flight.

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Watts, D. T. et al, Human Tolerance to Accelerations Applied from Seat to Head during Ejection Seat Tests; Pilot's Escape from High Performance Aircraft, Mechanism for Development and Test of-, Report No. 1, Project TED No. NAM 256005, Aero Medical Equipment Laboratory, Naval Air Experimental Station, Naval Air Material Center, Philadelphia, Pa.; ASTIA AD 206052, January 1947.

ABSTRACT: Average subjects have repeatedly ridden on the MBA 40", 52" and 60" catapults and have attained average velociti s of 55.4, 63.4, and 60.4 ft/sec respectively. Average maximum "G" recorded on the catapult seat and the hip, shoulder and head of subjects have been 17.4, 18.9, 18.5 and 17.0 "G" respectively. These accelerations have not resulted in significantly undesirable reactions and it is believed average aviation personnel could tolerate such accelerations with no injury.

The T-2 catapult with a much faster initial rate of acceleration produces unbalanced oscillations in the seat-cushion-subject mass system. This results in excessive accelerations recorded on the subject and man's limitation is approached while obtaining a maximum ejection velocity of 40 to 47.5 ft/sec.

No conclusions can be made as to the absolute optimum rate of seat acceleration for personnel ejection catapults. However, from the practical standpoint these experiments have shown that seat acceleration rates up to 100 "g" per second have not produced significant internal oscillations in the seat-cushion-subject mass with resultant excessive accelerations on the subject. Acceleration rates of 100 to 200 "g" per second begin to elicit excessive accelerations on the subject and rates of 200 to 700 "g" per second lead to such highly excessive acceleration on the subject that the performance of any catapult with a given stroke is definitely limited. This phenomenon might be controlled to some extent by the use of highly damped cushions, but the more logical point of control is in the catapult imparting the accelerations and it is believed the present seat parachute and cushion is a highly satisfactory cushioning system for ejection seats.

As shown under the condition of these experiments average men can safely tolerate the acceleration required to obtain adequate velocity for seat ejection. It is expected that other problems associated with seat ejection from aircraft can be solved. This is borne out by the live ejection of Lt. A. J. Furtek on 33 October 1946 at an IAS of 250 mph.

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Watts, D. T., et al, Evaluation of Face Curtain and Arm Rest for Use on Ejection Seats, Report No. 4, TED No. NAM 256005, Naval Air Experimental Station, Naval Air Material Center, Philadelphia, Pa., March 1947.

ABSTRACT: Experiments were conducted comparing arm rests and a face curtain for use on ejection seats. The curtain is pulled from above the head to the level of the sternum. This fires the catapult, restrains the head and partially supports the weight of the hands, arms and shoulders during the following acceleration. The curtain satisfactorily restrained the head and shoulders at accelerations from 17 to 21 G. With arm rests undesirable flexion of the body occurred at 10 to 12 G. Subjective reactions using the curtain were much less severe at the higher accelerations than they were at the lower values using the arms rests. It is concluded that the curtain is absolutely essential and is more protective than arm rests for use on ejection seats at accelerations up to 21 G.

260

Watts, D. T., et al, "Tolerance to Vertical Acceleration Required for Seat Ejection," J. Aviation Med., 18(6):554-564, 1947.

ABSTRACT: 1. The problem of bailing out of military aircraft and the desirability of the ejection seat as a means of escape are discussed. A 105-foot test rig and experimental procedures are described.

2. Results are given of sixty ejection seat experiments in which volunteer subjects were exposed to maximum acceleration in the range of approximately 18 to 21 G. It is concluded that, under the conditions of the experiments, average men can tolerate this acceleration, which is adequate to eject aviators from aircraft.

3. Careful recordings of catapult pressure and resultant accelerations were essential for the control and analysis of the forces to which personnel were exposed. Satisfactory instrumentation for this purpose has been assembled and its use described.

4. The dynamic response of the seat-cushion-subject mass to the suddenly applied ejection force is analyzed and discussed. This analysis has led to the improvement of existing catapults and the development of new and superior ejection devices.

261

Weinbren, M., "The Value of Tomography in the Examination of Fractured Vertebrae," Acta Radiol., Supplement 116, pp. 184-195, 1954.

ABSTRACT: 1. Although tomography has been an established procedure for many years, it has not been practised in the investigation of the spine as frequently as in the investigation of the chest, or other parts of the body.

2. Experimental work has shown that the defect in a vertebra has to be a certain size, before it can be demonstrated by routine radiography. Smaller defects can be demonstrated by tomography than by routine radiography.

3. There are certain regions of the spine in which tomography is obviously indicated. The atlanto-occipital region, the cervico-dorsal region, the upper and lower dorsal regions in particular, call for tomography, because the overlying shadows obscure the detail. Even in the lumbo-sacral region, tomography has been found of the greatest help.

4. Most of our tomograms are taken in the lateral position. We also take oblique and antero-posterior tomograms, particularly to show up the relationship of the articular facets.

5. We do not use any elaborate apparatus, but have in some instances, used high voltage tomography for the lumbo-sacral angle.

6. The features on which the diagnosis of a fracture may be made, and the features indicating consolidation of the fractures, fractures involving the body in the coronal plane, are described with the postmortem findings.

7. It is not sufficient to demonstrate the presence of a fracture of a body of the vertebra. The possibility that the fracture involves the spinal canal, has to be borne in mind, and closely investigated. Tomography is essential in the investigation of the spinal canal in various planes.

8. Occasionally "fragmentation" that is, small fragments of bone, are seen in association with spondylolisthesis. These fragments are seen in the gaps in the pars interarticularis of the involved lumbar vertebra. It is extremely difficult to determine whether these fragments of bone are the result of any recent injury, or are associated with the congenital defects which gave rise to the spondylolisthesis. The tomograms demonstrate these fragments of bone more clearly than the routine views. In the heavy patient, the small fragments of bone may be completely obscured in the routine radiographs.

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West, D. R., and J. T. Greenslade, Engineering Evaluation, Seat Separators, CEPE-RN-1622, Central Experimental and Proving Establishment, Canada, ASTIA AD 287009, May 1962.

ABSTRACT: In conventional jet aircraft such as the T33 or F86, employing a ballistic catapult type of ejection seat, man/seat separation is accomplished by the difference in aerodynamic drag forces and masses of the seat/man. The actual time of separation under these conditions will be a function of the speed at which ejection occurs and the orientation of the seat/man package after ejection. These conditions render the seat/man separation time predictable only within a relatively broad range, and in the low altitude, low forward speed case, a delayed separation could cause a critical collision to occur between the man and seat. The introduction of a man/seat separating device, programmed to separate the crew member positively from his seat at a specific time, will reduce the separation time normally encountered when drag/mass ratio is the controlling factor. This would eliminate the collision probability by providing a safe distance between the man and the seat when parachute deployment occurs. Elimination of delay in separation will permit an over-all decrease in the escape system's functioning time and thus provide an improvement in height-above-ground recovery capability. Ballistically operated man/seat separator actuators were obtained and efficiently used in aircraft pilot seat and back cushions. The combined advantages of lighter weight, solvent resistance, and closer quality control indicate that the polyurethane foams offer a superior body support material.

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Whitlock, C. M., Jr., Human Vertebral Column Alignment under Physical Loads, Convair Aircraft Company, San Diego, California, 1957.

ABSTRACT: The normal human vertebral column is oriented in a somewhat buckled position. Determination of optimum vertebral column positions for various load applications to the human being is a complex human engineering problem in which a number of parameters must be balanced to get the best position for any given loading. The analysis of optimum vertebral column loading, for at least one type of load condition, is reported. This will include description of structural intricacies, the types of failures possible with them, results of x-ray analysis and design recommendations therefrom.

264

Wiesehoefer, H., "Aviation Medical Principles for the Construction of Emergency Ejection Seats," The Ejection Seat for Emergency Escape from High-Speed Aircraft, Appendix 2, ASTIA ATI 7245, 31 August 1945.

ABSTRACT: Following a review of the dynamic processes occurring in the ejection of the catapult seat, the effects on the human subject resulting from accelerations and air resistance are set forth. The limiting conditions are established under which the thresholds of tolerance of the human body, and particularly of the spinal column, are not exceeded. The procedures for reducing the forces involved and certain safety measures are discussed.

I. Introduction
II. Technical Details of the Ejection Seat.
III. Tolerance Toward Impact-Like Accelerations.
IV. Experiments on Tolerance to Wind Blast.
V. Flight Tests with Catapult Seat in the Ju 87.
VI. Possible Methods of Reducing the Acceleration During Ejection.

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Wiesehoefer, H., "Catapult Seat Ejection with Human Subjects: Tolerance to Acceleration of Persons Ejected from the Do-335 and He-219," The Ejection Seat for Emergency Escape from High-Speed Aircraft, Appendix 14, ASTIA ATI 7245, 31 August 1945.

ABSTRACT: The report deals with the effects on human subjects of seat ejection from a stationary mounting using high driving forces.

Using a catapult seat assembly intended for model Do 335, twenty-seven ejections have been performed with ten subjects, using pressures of 60 to 135 atmospheres. Using that intended for model He 219, fourteen ejections have been made with five subjects at pressures of 60 to 90 atmospheres.

Attention is drawn to the differences between the two assemblies; the requirements for each are set forth, and the results of the experiments are discussed.

266

Wiesehoefer H., "Aero-Medical Basis for Construction of Catapult Seats (Flugmedizinische Grundlagen Zum Ban Von Schleudersitzen), ASTIA ATI 52016, October 1943.

ABSTRACT: A detailed discussion is presented on the aero-medical principles for construction of catapult seats. The main topic of the discussion is the determination of how well the human body is able to withstand the strain connected with high acceleration, and how these stresses can be reduced, and other safety measures are outlined. Numerical tables are given showing the stress resistance of

various vertebrae to various stresses. One proposed measure to reduce acceleration is to catapult the seat downward. Results of tests showed that accelerations of 18 to 20 g for a period of 1/10 to 2/10 sec are permissible causing no serious effects to the body.

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Wiesehoefer, H., "Tolerance of Human Subjects to Acceleration during Catapult Seat Ejection (Schleudersitzabechuesse mit Menschen zur... Flugzeugmuster), ASTIA ATI 43761, October 1944.

ABSTRACT: Tests were performed with catapult ejection seats with human subjects to determine tolerance to high acceleration. Catapult seats intended for the Do 335 and He 219 fighters were used, at ejection pressures of 60 to 135 atmospheres corresponding to actual flight of both aircraft. Attention is directed to the difference in construction of both assemblies. On the basis of results obtained it is shown that these ejection seats may be used without causing injuries to pilots due to excessive acceleration. It is considered premature to regard accelerations up to 28 g, which have been well tolerated in the tests, as lying invariably below the breaking load of skeletal structures.

268

Wilbur, C. E., "U.S. Navy Operational Experience with Ejection Seat Escape," J. Aviation Med., 28:64-68, February 1957.

ABSTRACT: There are many variables involved in any successful ejection, the principal ones being: (1) the condition of the aircraft, including its altitude and speed; (2) the functioning of the ejection seat mechanism, including separation from the seat and deployment of the parachute; and (3) the reactions of the pilot, including his decision to eject and his ability to complete the required procedure.

It is difficult in each instance of ejection to isolate the variable factors at fault. For this reason, each individual ejection should be considered as an occurrence in itself for purposes of safety study and preventive action. Furthermore, it is not possible in a series of only 177 cases to be on firm statistical ground.

Although the ejection system has been relatively safe in flight, its extra safety factors may have introduced undesirable features into escape under extreme emergency conditions. The seat cannot be fired until the canopy is jettisoned and thus pulls the seat catapult safety pin. This provision prevents premature ejection through a closed or partially opened canopy. However, since in this system failure of the canopy ejection mechanism would mean inability to eject with possible fatal results, a device for alternate removal of the safety pin has been incorporated to allow ejection through the canopy. The remaining major

areas for reduction of fatalities lie in increasing the probability of successful escape at low altitudes, and at very high altitudes and speeds.

(The paper presents several graphs and many statistics concerning speed during escape, cause of ejection, and survival rate of ejected pilots)

The 177 ejection escapes from Naval aircraft since 1949 are reviewed with respect to the circumstances associated with them. Significant survival percentages are: 96% for ejections above 5000 ft., 7% for ejections below 1000 ft., 90% for ejections below 400 knots, and 55% for ejections above 500 knots. Desirable and undesirable features of the Navy's "face curtain fired" ejection seat are also reviewed.

269

Wilkes, W. H., "Escape from Multiplace Supersonic Aircraft," presented at the Symposium on Problems of Emergency Escape in High Speed Flight, Wright-Patterson Air Force Base, Ohio, 29-30 September 1952.

ABSTRACT: The principal dangers involved in escape from an aircraft at supersonic speeds and high altitudes are as follows: (1) explosive decompression; (2) immobility due to uncontrollable airplane or injury; (3) possibility of collison with the airplane structure such as wings, fin, wheels, etc.; (4) possible high temperatures due to aerodynamic heating of the crewman; (5) extreme horizontal deceleration after entering the airstream; (6) physical harm due to air blast on face and body; (7) lack of oxygen; (8) extreme cold; and (9) inability to open the parachute due to unconsciousness. The implications of these dangers are briefly discussed, in as much as they apply to multiplace bombers operating at altitudes up to 60,000 feet and speeds up to Mach 2.

270

Woodward, C., et al. Investigation, Design and Development of an F7U-3 Ejection Seat Energy-Absorption for Reduction of Crash Force Loads, NAMC-ACEL-335, Air Crew Equipment Laboratory, Naval Air Material Center, Philadelphia, Pennsylvania, 24 June 1957.

ABSTRACT: Spinal Injuries resulting from failure of the nose landing gear during carrier landings caused an investigation of the forces involved and research into a method of reducing these forces.

A simulated crash test determined that forces along the vertical plane of the seat, corresponding to forces in the vertical plane of the spinal column, were far in excess of the tolerable limits of the human body. An energy-absorption system, consisting of a stainless steel strap with attaching devices, coupled with an energy-absorbing seat cushion, was devised and tested.

271

Young, R. D., "Note on the Flight Path of a Man Ejected Normally from an Aeroplane Moving at a High Speed," The Ejection Seat for Emergency Escape from High Speed Aircraft, Appendix 7, ASTIA ATI 7245, 31 August 1945.

ABSTRACT: Calculations have been made of the flight path of a man ejected normally from an aeroplane moving at speeds (U_o) of 400 f. p. s., and 800 f. p. s. Ejection velocities (V_o) of 20 f. p. s., 50 f. p. s. and 100 f. p. s. in both up and down directions have been considered for each case, and the calculations are sufficiently valid for practical requirements. It is concluded that an upward ejection velocity of about 40 f. p. s. should be sufficient in most cases for the man to clear the aeroplane structure. The initial acceleration on the man required to give him this ejection velocity is estimated to be about 12 1/2 g acting for 1/10th sec.; this is not considered serious. The power required can be readily provided by a few ounces of cordite.

272

Zeller, A. F., "Physiologic Factors in Escape," J. Aviation Med., 28:90-95, 1957.

ABSTRACT: The ejection sequence begins with perception of the situation, involves a decision as to the action to be taken, and is followed by the initiation of the action. It can serve as a vehicle which can be used to analyze the various steps of the entire ejection procedure in terms of the important psychologic variables which affect the individual's behavior during this procedure.

The first step in the decision to initiate the ejection procedure is dependent upon recognition of the emergency. One other consideration which is important in the decision to eject in multi-place aircraft is adequate knowledge by other crew members of the action being taken by the pilot.

Difficulties during ejection include unfamiliarity with ejection equipment and loss of consciousness or perspective after ejection. The general feeling of confidence a pilot has in the basic equipment which he is flying and in his ejection equipment can be spoiled by adverse criticisms.

One of the best preparations for an ejection should be an actual previous ejection in which the pilot has been successful. Somewhat less critical training experience is obtained from the ejection tower, demonstrations and lectures. One other overall factor associated with ejection escape is the pilot's total flying experience. This to a great extent reflects his background and maturity as a pilot.

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Zeller, A. F., The Decision to Eject, Life Sciences Group, Directorate of Aerospace Safety, Norton Air Force Base, California, 1964.

ABSTRACT: The increasing number of aircraft equipped with ejection systems makes it desirable that there be an evaluation of the wisdom with which this equipment is used. All major United States Air Force aircraft accidents for a recent calendar year were examined in which crewmen ejected as well as those in which they did not.

Conditions associated with the accident as well as the results were compared for the two groups. With some glaring exceptions, crewmen consistently chose the course of action conducive to both personal survival and minimum loss of equipment.